

WL-TR-93-1164

DEVELOPMENT OF LARGE AREA, TILED,
LIQUID CRYSTAL DISPLAY

AD-A277 564



N. MAZUREK
T.J. ZAMMIT

MAGNASCREEN CORPORATION
159 GILBRALTAR ROAD
HORSHAM PA 19044

DECEMBER 1993

FINAL REPORT FEBRUARY 1992 to DECEMBER 1993

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION IS UNLIMITED.

DTIC
S **ELECTE** **D**
F
MAR 29 1994



94-09543



AVIONICS DIRECTORATE
WRIGHT LABORATORY
AIR FORCE MATERIEL COMMAND
WRIGHT PATTERSON AFB OH 45433-7409

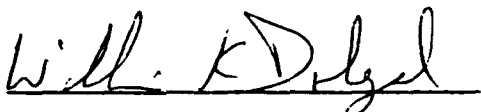
94 3 28 099

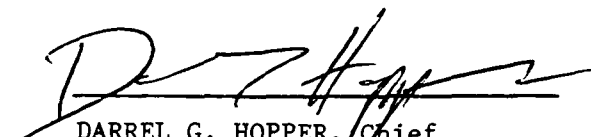
NOTICE

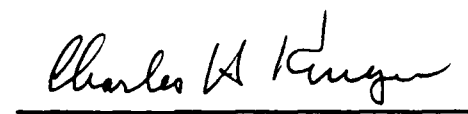
When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely Government-related procurement, the United States Government incurs no responsibility or any obligation whatsoever. The fact that the government may have formulated or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication, or otherwise in any manner construed, as licensing the holder, or any other person or corporation; or as conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

This report is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.


WILLIAM K. DOLEZAL, Proj. Eng.
Cockpit Avionics Office
Avionics Directorate


DARREL G. HOPPER, Chief
Cockpit Avionics Office
Avionics Directorate


CHARLES H. KRUEGER, Chief
System Avionics Division
Avionics Directorate

If your address has changed, if you wish to be removed from our mailing list, or if the addressee is no longer employed by your organization please notify WL/AAA, WPAFB, OH 45433-7409 to help us maintain a current mailing list.

Copies of this report should not be returned unless return is required by security considerations, contractual obligations, or notice on a specific document.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave blank)		2. REPORT DATE DEC 1993	3. REPORT TYPE AND DATES COVERED FINAL Feb 92 to Dec 93	
4. TITLE AND SUBTITLE DEVELOPMENT OF LARGE AREA, TILED, LIQUID CRYSTAL DISPLAY			5. FUNDING NUMBERS C F33615-92-C-3806 PE 62708 PR DARK TA 02 WU 09	
6. AUTHOR(S) N. MAZUREK T.J. ZAMMIT				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) MAGNASCREEN CORPORATION 159 GILBRALTAR ROAD HORSHAM PA 19044			8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) AVIONICS DIRECTORATE WRIGHT LABORATORY AIR FORCE MATERIEL COMMAND WRIGHT PATTERSON AFB OH 45433-7409			10. SPONSORING / MONITORING AGENCY REPORT NUMBER WL-TR-93-1164	
11. SUPPLEMENTARY NOTES				
12a. DISTRIBUTION / AVAILABILITY STATEMENT APPROVED FOR PUBLIC RELEASE; DISTRIBUTION IS UNLIMITED.			12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words) This document presents the results of the development of a large area, tiled, liquid crystal display system, seamless in appearance. Magnascreen demonstrated the feasibility of using an array of smaller, cost effective LCDs to create a large display seamless in appearance. The vehicle chosen for demonstrating the system was a 1.3M (51") VGA monitor design. A 3 x 2 array was fabricated to verify the system design concept.				
14. SUBJECT TERMS LCD, flat panel, seams, tiled			15. NUMBER OF PAGES 81	
			16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT UNCLASSIFIED	18. SECURITY CLASSIFICATION OF THIS PAGE UNCLASSIFIED	19. SECURITY CLASSIFICATION OF ABSTRACT UNCLASSIFIED	20. LIMITATION OF ABSTRACT UL	

DEVELOPMENT OF A LARGE AREA, TILED, LIQUID CRYSTAL DISPLAY

TABLE OF CONTENTS

	<u>PAGE NO.</u>
LIST OF FIGURES	v
LIST OF TABLES	vi
SUMMARY OF PROPRIETARY CLAIMS	1
1.0 INTRODUCTION	2
1.1 BACKGROUND	2
1.2 PROGRAM OBJECTIVE	2
1.3 PROGRAM DESCRIPTION	3
1.4 PROGRAM RESULTS & CONCLUSIONS	6
1.5 FUTURE PROGRAM OBJECTIVES	6
2.0 SYSTEM DESIGN	8
2.1 SYSTEM DESIGN APPROACH	8
2.2 LCD DESIGN	8
2.3 MECHANICAL DESIGN	12
2.4 LCD MODULE	19
2.5 BACKLIGHT DESIGN	21
2.6 OPTICAL DESIGN	21
2.7 ELECTRONIC DESIGN	23
3.0 SYSTEM PROTOTYPE RESULTS	29
3.1 LCD PROTOTYPE FABRICATION	29
3.1.1 PROCESS DEVELOPMENT	29
3.1.2 PROTOTYPE FABRICATION	29
3.1.3 REMAINING LCD PROCESS DEVELOPMENT & FABRICATION ISSUES	30
3.2 MECHANICAL ASSEMBLY	30
3.3 TILE ASSEMBLY	32
3.4 BACKLIGHT ASSEMBLY	32
3.5 COLOR FILTER DEVELOPMENT	45
3.6 OPTICAL PERFORMANCE	45
3.6.1 SEAMLESS APPEARANCE	45
3.6.2 LCD OPTICAL PARAMETERS	58
3.6.3 OVERALL DISPLAY PERFORMANCE ISSUES	58
3.7 ELECTRONIC ASSEMBLIES	62

Accession For	
NTIS CRA&I	<input checked="" type="checkbox"/>
DTIC TAB	<input type="checkbox"/>
Unannounced	<input type="checkbox"/>
Justification	
By	
Distribution/	
Availability Codes	
Dist	Avail and/or Special
A-1	

**DEVELOPMENT OF A LARGE AREA,
TILED, LIQUID CRYSTAL DISPLAY**

TABLE OF CONTENTS (cont'd.)

	<u>PAGE NO.</u>
4.0 FUTURE SYSTEM DEVELOPMENTS	64
4.1 LCD OPTIMIZATION	64
4.1.1 PROTOTYPE LCD OPTIMIZATION	66
4.1.2 STN EVALUATION	66
4.1.3 AMLCD SOURCING	67
4.2 BACKLIGHT OPTIMIZATION	67
4.3 COLOR FILTER OPTIMIZATION	67
4.4 FRONT DIFFUSER DEVELOPMENT	68
4.5 MECHANICAL REGISTRATION OPTIMIZATION	69
4.6 PRODUCT PROTOTYPE DEVELOPMENT	69
5.0 POTENTIAL PRODUCTS AND MARKETS	70
5.1 POTENTIAL PRODUCTS	70
5.2 POTENTIAL MARKETS	70

DEVELOPMENT OF A LARGE AREA, TILED, LIQUID CRYSTAL DISPLAY

LIST OF FIGURES

<u>FIGURE</u>	<u>DESCRIPTION</u>	<u>PAGE NO.</u>
1.3-1	VGA Display System	5
2.1-1	Interpixel Spacing Concept	9
2.2-1	Edge Contact Design	11
2.2-2	Detailed Pixel Design	13
2.2-3	Row & Column Artwork Electrode Design	14
2.2-4	Sputter Mask Design	15
2.3-1	Base Plate System Design	17
2.3-2	Center Position Concept	18
2.3-3	LCD Module Alignment Method	20
2.4-1	LCD Module Backlight Design	22
2.6-1	Stack-up of Optical Components	24
2.7-1	Block Diagram of System Electronics	26
2.7-2	Block Diagram Inter-Electronics	27
3.2-1	3 x 2 Unit Base Plate Photographs	33
3.3-1	Tile Assembly Fixture Photograph	34
3.4-1	Graph of the Measurements of Horizontal & Vertical Edges	36
3.4-2	Light Box Cover Modifications	38
3.4-3	Patterned Diffuser Design	39
3.4-4	Light Uniformity Measurements (after corrective action)	40
3.4-5	Measurements of Fan Cooling Effectiveness	41
3.4-6 & 3.4-7	Heat Rise Within Module	42,43
3.4-8	3 x 2 Unit Backlight System Photograph	44
3.6.1-1 to -4	Photos of Graphic Images Displayed on 3 X 2	46-49
3.6.1-5	Photos of Pixels at LCD Module Seams	51
3.6.1-6	Measurements of LCD Transmission	53
3.6.1-7 & -8	Measurements of 3 X 2 Edge Luminance	54,55
3.6.2-2	Typical Contrast & Transmission	60
5.1-1	640 x 480 VGA System Mock-up Photograph	71
5.2-1	Potential Market and Pricing	73
5.2-2	Potential Market vs. LCD Technology	74

***DEVELOPMENT OF A LARGE AREA,
TILED, LIQUID CRYSTAL DISPLAY***

LIST OF TABLES

<u>TABLE</u>	<u>DESCRIPTION</u>	<u>PAGE NO.</u>
3.1.2-1	Batch Process Yield Results	31
3.6.1-9	Typical Parameters	56
3.6.2-1	LCD Optical Parameters	59
4.0-1	Tiled Display System/Performance vs. Key Elements	65

DEVELOPMENT OF A LARGE AREA, TILED, LIQUID CRYSTAL DISPLAY

SUMMARY OF PROPRIETARY CLAIMS

Magnascreen's proprietary claims on results, prototypes, or systems that are supporting, and/or necessary for the use of research results, and/or prototypes, include:

- Thin Seal LCD Technology - This includes the design and manufacturing processes for minimizing the epoxy seal width of conventional LCD assemblies.
- Edge Connection Technology - This includes the design and manufacturing processes for replacing conventional LCD electrical contacts with electrical contacts on the edge of the LCD assembly.
- Color Filter Technology - This includes the development of a large area, precision, external LCD color filter.
- Optical Lighting Technology - This includes the design and manufacturing of a lighting system that provides uniform backlighting for arrays of tiled LCDs.
- Large Area Display Mechanical Alignment System - This includes the mechanical design and assembly process for configurable arrays of LCD tiles to be mounted and precisely aligned into a seamless array.

In order to assure maximum opportunity for financial success in our respective business, MSC wishes to retain rights to present and future proprietary materials, processes and hardware which may be involved in this program, including:

- All patents already applied for by MSC,
- All disclosures in MSC's figuring books not yet filed, and
- All patentable items arising from the proposed work, whether filed during the period of the contract, or afterward.

Magnascreen, under suitable circumstances and appropriate terms, is willing to license technologies developed to other companies. Specifically, Magnascreen has interest in developing arrangements with suitable LCD manufacturers who can implement Magnascreen's proprietary processes for LCD fabrication.

DEVELOPMENT OF A LARGE AREA, TILED, LIQUID CRYSTAL DISPLAY

1.0 INTRODUCTION

1.1 BACKGROUND

Magnascreen Corporation was awarded Contract F33615-92-C-3806 by WPAFB, in July 1992, to develop and demonstrate a large area, tiled, liquid crystal display (LCD) system design that is seamless in appearance.

The need for large area, direct view, display systems continues to exist for both commercial and military applications. These applications require luminance and contrast sufficient for viewing in varied ambient lighting conditions, image linearity, and the relatively thin profile of a "picture on the wall" difficult to obtain with projection systems.

LCD technology continues to be one of the best potential solutions for direct view, large area display system applications. However, processing difficulties currently and for the foreseeable future limit display size well below the minimum goal of one meter diagonal.

The obvious solution to developing large area LCD systems is to tile arrays of smaller manufacturable tiles (LCD modules). The extremely difficult technical challenge is to create a tiled large area display that is "seamless" in appearance.

Magnascreen, under a previous DARPA Contract MDA972-90-C-0032, did considerable research to develop and understand the tiled display system requirements for a large area LCD seamless in appearance. Polymer dispersed liquid crystal (PDLC), active matrix and passive matrix LCD technologies were evaluated.

Based on the results of Contract MDA972-90-C-0032, and Magnascreen's development of a "thin seam" LCD manufacturing process, a program was proposed to develop and demonstrate a practical and cost effective large area, tiled, LCD system seamless in appearance.

This final report documents the large area, tiled, LCD system developed, and the results of the prototype demonstrated.

1.2 PROGRAM OBJECTIVE

The program objective was to design, develop, and prototype a manufacturable and cost effective large area LC display system, seamless in appearance, using the concept of tiling.

The tiled LCD system developed is intended to be the basis for a range of commercial and military products and applications.

The defined system features and design constraints for the large area display system included:

DEVELOPMENT OF A LARGE AREA, TILED, LIQUID CRYSTAL DISPLAY

SYSTEM FEATURES

Based on the product applications of the tiled LCD system, Magnascreen defined the following features:

- Sufficient resolution to make the screen size practical for typical indoor applications now filled by projection systems. Specifically, diagonal display sizes of 1.3m to 2.6m (50"-100"), that provide from 640 X 480 to 1280 X 1024 total display lines.
- Sufficient optical performance to provide a readable color display in typical room ambient lighting conditions.
- A configurable and scalable system design that can be used for a variety of application display sizes and formats.
- System size and weight that is compatible with the "picture on the wall" concept.
- A system design that is practical to maintain and repair. This includes the ability to easily relamp the unit where it is being used and the ability to replace an individual LCD module at a typical maintenance shop.

DESIGN CONSTRAINTS

The design constraints of the system to meet the program objective included:

- The use of available cost effective LCD technology that Magnascreen could prototype in-house.
- A mechanical design whose components can be readily fabricated by standard manufacturing processes (i.e., CNC machining, molding, etc.).
- A backlight design that uses standard commercially available lamps.
- The use of "standard off the shelf" electronic components, specifically in the area of LCD drivers and controllers.

1.3 PROGRAM DESCRIPTION

The program to develop a tiled large area display system consisted of the following elements:

- Development of the system design parameters required to meet the program objective.
- Detailed design of the system components.
- Refinement of Magnascreen's "thin seam" LCD manufacturing process.

DEVELOPMENT OF A LARGE AREA, TILED, LIQUID CRYSTAL DISPLAY

- Fabrication of a test bed consisting of a 3 X 2 array of LCD modules to evaluate the system design parameters and the individual components fabricated.
- Refinement of the system design and components based on the evaluation of the 3 X 2 unit.
- Fabrication of a 1.3M (51") diagonal, 48 LCD module, 640 X 480, VGA display as a product demonstration vehicle.

Figure 1.3-1 illustrates the VGA display system.

The design and development portion of the program was intended to last 10 months with delivery of the 1.3M (51") display system and final report at the end of 14 months.

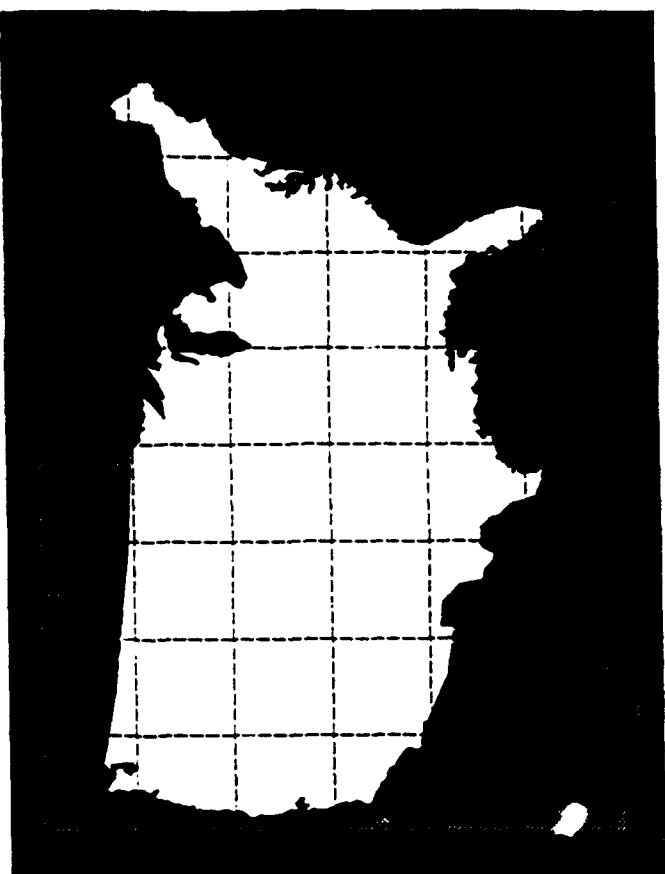
DESIGN AND DEVELOPMENT AREAS

The program included the following detailed design and development tasks:

- Development and specification of the LCD parameters required to create a seamless display appearance.
- Development of tooling and processes to implement the "thin seal" and "edge contact" LCD technologies required for the seamless display design.
- Design and development of an LCD module to be used as a system tile.
- Design and development of a mechanical registration system to accurately retain the LCD modules.
- Design and development of a global fluorescent backlight system.
- Design and development of optical elements (color filters, global black surround mask, diffusers, etc.)
- Design and development of LCD driver, LCD controller, and display interface electronics.

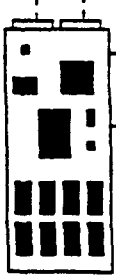
ADDITIONAL PROGRAM ELEMENTS

Additional elements of the program included:



51" DIRECT VIEW LCD (640x480) COLOR DISPLAY

OPTIONAL, CRT DISPLAY
VGA ANALOG



VGA COMPATIBLE LCD DISPLAY INTERFACE CARD

IBM PC COMPATIBLE,
16-BIT ISA BUS,
HOST SYSTEM

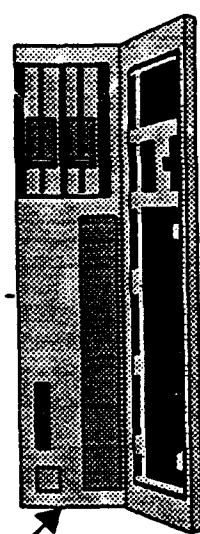


FIGURE 1.3-1: VGA DISPLAY SYSTEM

DEVELOPMENT OF A LARGE AREA, TILED, LIQUID CRYSTAL DISPLAY

- Detailed documentation of the design developed.
- Detailed optical evaluation of the system.
- System performance test and evaluation.
- Evaluation of potential commercial and government markets and applications for the display system developed.

1.4 PROGRAM RESULTS & CONCLUSIONS

The results, conclusions and status of the tiled display development program at the time of this final report can be summarized as follows:

- The basic large area tiled system design has been completed and demonstrated via a display comprised of a 3 X 2 array of LCD modules (48cm (19") diag).
- The feasibility of a tiled display seamless in appearance has been demonstrated.
- The key system features defined at the start of the program have been demonstrated.
- The proprietary "thin seam" LCD process has been developed and hundreds of prototype LCD's fabricated.
- The potential for cost competitive display products has been verified by developing system components within the program design constraints.
- The optical performance of the system must still be optimized for commercial product quality.
- The 1.3M (51") VGA design was completed; mechanical, electronic and backlight components fabricated; final assembly and test of the unit requires the fabrication of an optimized LCD.

1.5 FUTURE PROGRAM OBJECTIVES

The future program objectives are based on the goal of commercializing the tiled large area display system developed into products. These include:

- LCD optimization
 - Prototype optimization
 - STN evaluation and development
 - AM LCD sourcing
- Backlight optimization

DEVELOPMENT OF A LARGE AREA, TILED, LIQUID CRYSTAL DISPLAY

- Color filter optimization
- Front diffuser development
- Mechanical registration optimization
- Product prototype development

Section 4.0 provides additional details on these future developments.

DEVELOPMENT OF A LARGE AREA, TILED, LIQUID CRYSTAL DISPLAY

2.0 SYSTEM DESIGN

The following sections describe the design developed for the large area, tiled, LCD system:

2.1 SYSTEM DESIGN APPROACH

The system design approach developed by Magnascreen for a tiled display system to appear seamless was:

- The inter-pixel spacing between two adjacent LCD modules in the array would be the same as the interpixel spacing within an LCD module.

Figure 2.1-1 illustrates this inter-pixel spacing concept.

- The minimum distance between pixels on adjacent LCD modules and a minimum fill factor of 50% would define the maximum display lines per inch.
- The mechanical inter-module seams of the display would be hidden by a global black mask that covers the entire array of LCD modules.
- Each LCD module would have an "X Y" and rotational mechanical positioning system to allow the individual LCD modules to be positioned within the global black mask.
- A global mechanical plate would be used to mount and maintain the array of LCD modules in position.
- A global fluorescent LCD backlight design would be used to provide a continuous light source of constant intensity and color.
- The LCD drive electronics would allow the transmission of individual tiles to be varied to create a uniform display appearance.

The detailed component designs were based on the above system approach within the design constraints previously defined.

2.2 LCD DESIGN

The key to Magnascreen's large area, tiled, LCD design is the development of an LCD manufacturing process that minimizes the distance between the edge of the glass and the active display area.

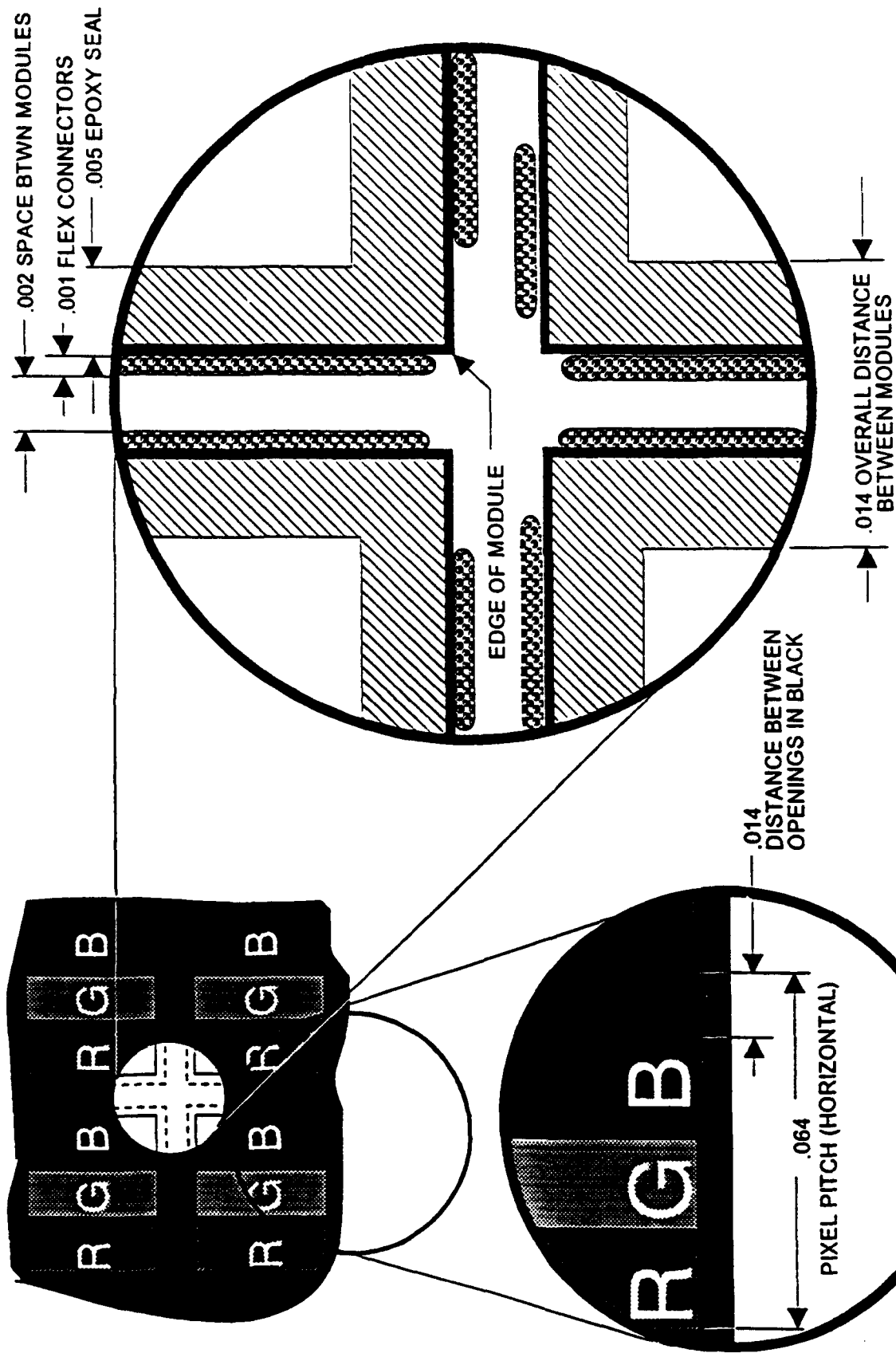


FIGURE 2.1-1: INTERPIXEL SPACING CONCEPT

DEVELOPMENT OF A LARGE AREA, TILED, LIQUID CRYSTAL DISPLAY

This consists of a "thin seal" manufacturing process which reduces the epoxy seal width to 0.13mm (0.005"), and an "edge contact" manufacturing process which eliminates the need for a typical contact ledge. The use of these manufacturing technologies permits the active display area to be located within 0.13mm (0.005") of the glass edge.

Figure 2.2-1 illustrates the "edge contact" design.

Based on these manufacturing processes, the following LCD design was developed.

LCD CONFIGURATION

The LCD configuration was selected to satisfy the following main requirements:

- 1) To provide sufficient optical performance to demonstrate seamless tiled display system feasibility.
- 2) To be compatible with Magnascreen's in-house prototype fabrication capability.
- 3) To have the optical performance potential for commercial products once optimized.

The use of basic TN LCD technology in a dual cell configuration met these requirements.

The LCD configuration can be summarized as follows:

- Passive TN LCD technology
- Second minima cell spacing
- Monochrome
- 40:1 multiplex rate
- Dual cell; three (3) polarizer filter configuration
- Normally dark operation
- Two page (upper page/lower page) format

LCD TILE MECHANICAL SPECIFICATION

The mechanical specifications are a basic result of the seam size and minimum acceptable fill factor toleranced for thermal expansion of the system components. Other constraints, such as edge contact density, color filter parallax, backlight fluorescent tube diameters and the flex circuit design were also satisfied.

The mechanical specification for the LCD module can be summarized as follows:

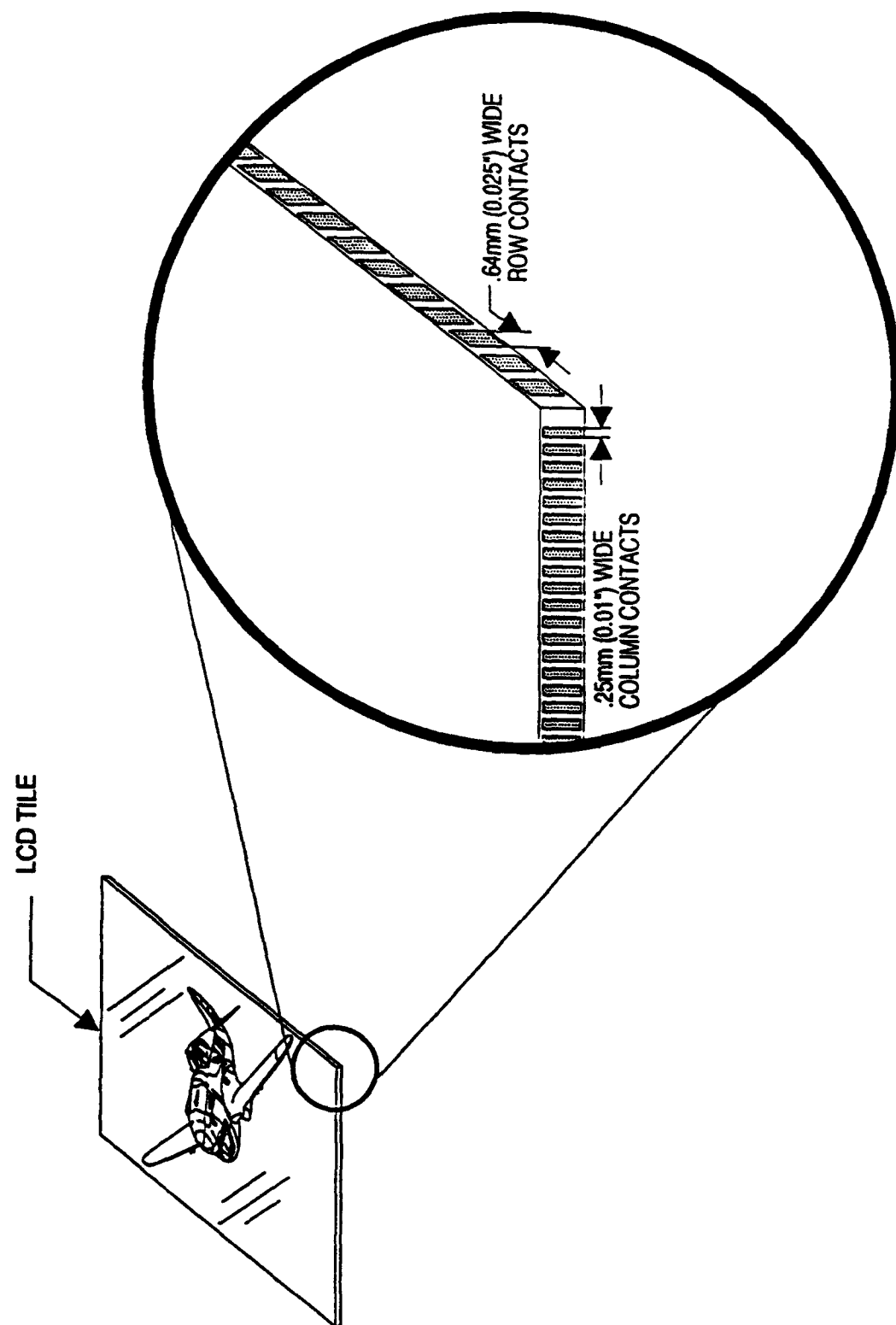


FIGURE 2.2-1: EDGE CONTACT DESIGN

DEVELOPMENT OF A LARGE AREA, TILED, LIQUID CRYSTAL DISPLAY

- Glass size: 130mm (5.119") X 130mm (5.119") X 2.5mm (0.1")
- Electrode configuration: 80 rows X 240 columns
- Pixel configuration: 80 X 80 color pixels; R,G,B stripes
- Color pixel pitch: 1.63mm (0.064") X 1.63mm (0.064")
- Color pixel size: 1.37mm (0.054") X 1.37mm (0.054")
- 6.1 lines/cm (15.6 color lines per inch)

Figure 2.2-2 illustrates the detailed pixel design.

LCD TOOLING

The LCD tooling developed specific to this design included:

- Chrome masters of the row, column and edge contact area artwork fabricated to the following specifications:
 - 0.08mm (0.003") minimum line widths
 - 0.08mm (0.003") minimum line spaces

Figure 2.2-3 illustrates the row and column artwork electrode design.

- Two (2) edge contact sputter masks were fabricated by EDM and chemical etching processes. They are:
 - Row mask: 80 [0.64mm (0.025") wide] edge contacts
 - Column mask: 480 [0.25mm (0.01") wide] edge contacts

Figure 2.2-4 illustrates the sputter mask design.

2.3 MECHANICAL DESIGN

The main function of the mechanical design for the tiled system was to accurately register the individual LCD modules to a global black mask and retain their position over time and temperature.

BASE PLATE SYSTEM

A base plate system was developed for the mechanical design. The system consists of the following elements:

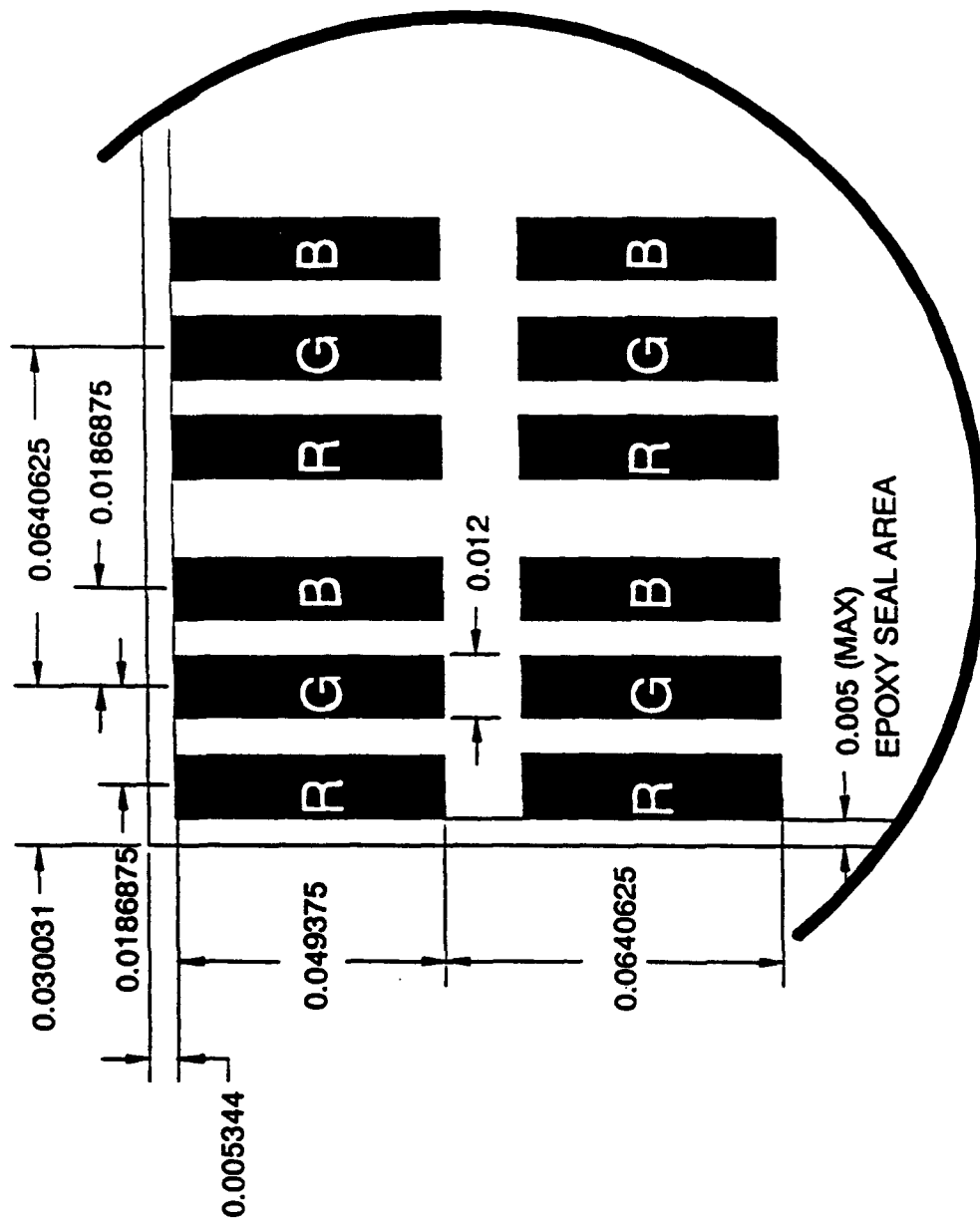
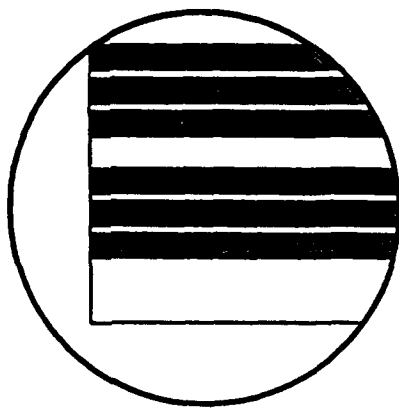
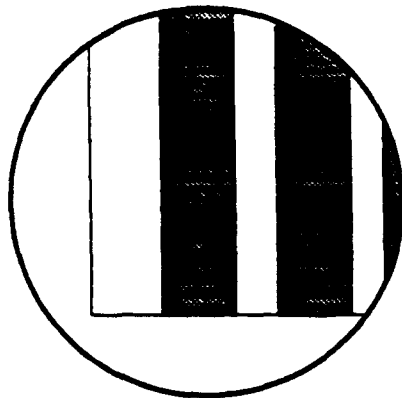


FIGURE 2.2-2: DETAILED PIXEL DESIGN

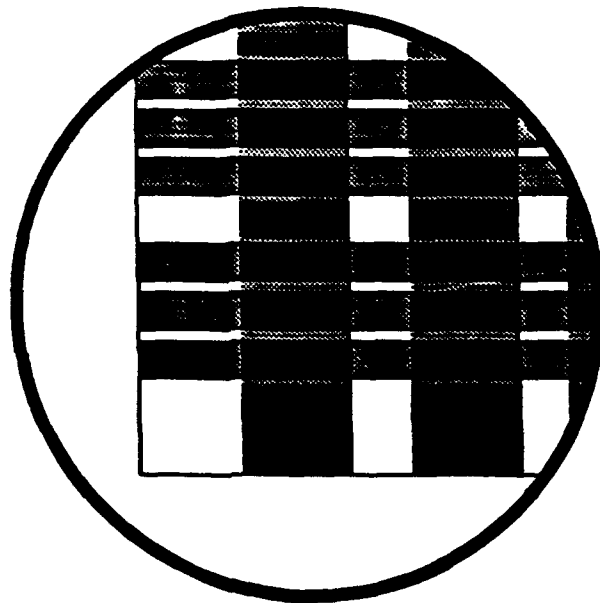
COLUMN ELECTRODES



ROW ELECTRODES



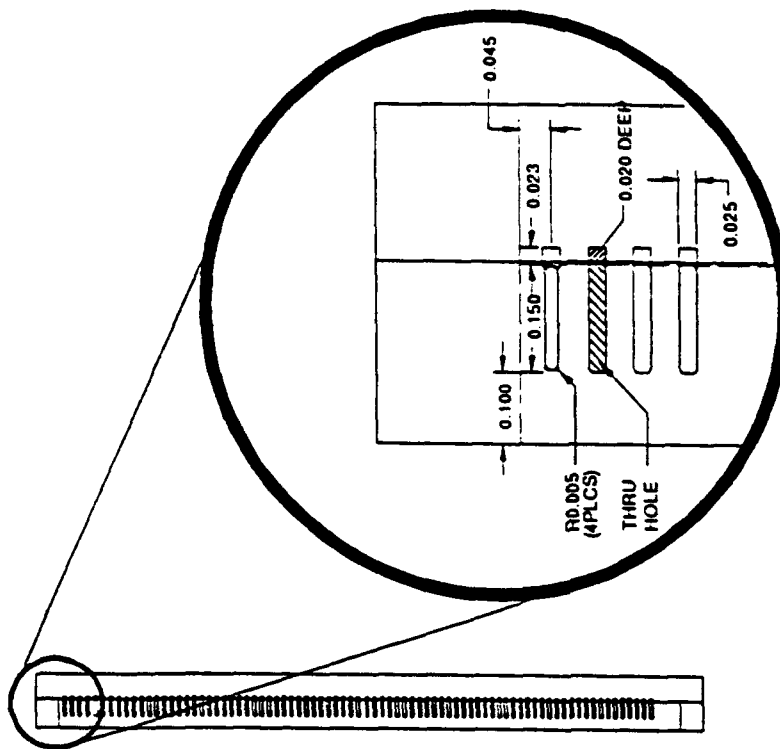
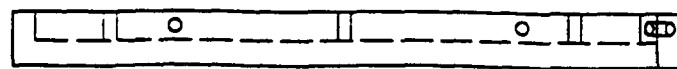
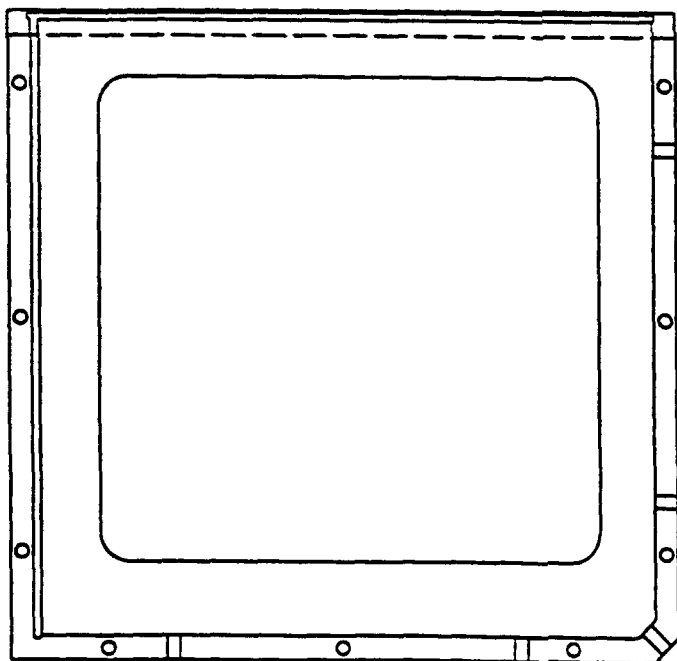
**OVERLAP
PRODUCING PIXELS**



**FIGURE 2.2-3: ROW & COLUMN ARTWORK
ELECTRODE DESIGN**



MAGNASCREEN



MAGNASCREEN

FIGURE 2.2-4: SPUTTER MASK DESIGN

DEVELOPMENT OF A LARGE AREA, TILED, LIQUID CRYSTAL DISPLAY

- A large single plate that provides mounting for:

- The array of LCD modules
- Bezel assembly
- Rear plate
- Fluorescent backlight system
- Interface electronics

- A bezel assembly consisting of:

- Cover glass
- Global black mask
- Global diffusing screen

- A rear plate that provides:

- Mounting for fluorescent ballasts
- Power supplies
- Attachment points for wall mounting

- A cover that:

- Encloses the entire display unit
- Contains cooling fans

Figure 2.3-1 illustrates the base plate system design.

The mechanical system functions as follows:

- The individual LCD modules are secured to the base plate, located independently of each other, at their center positions. This allows for replacement of individual LCD modules without affecting the alignment of other LCD modules in the array.
- The center mounting of each LCD module allows mechanical position of each tile over time and temperature to be a function of the base plate material characteristics. The more stable the base plate material the more stable the entire display system.

Figure 2.3-2 illustrates the center position concept.

- The bezel assembly is mounted to the front of the base plate and held against the face of the LCD modules by spring tension. The spring tension maintains direct contact between the black mask and individual LCD modules independent of thermal expansion or contraction of the LCD modules.

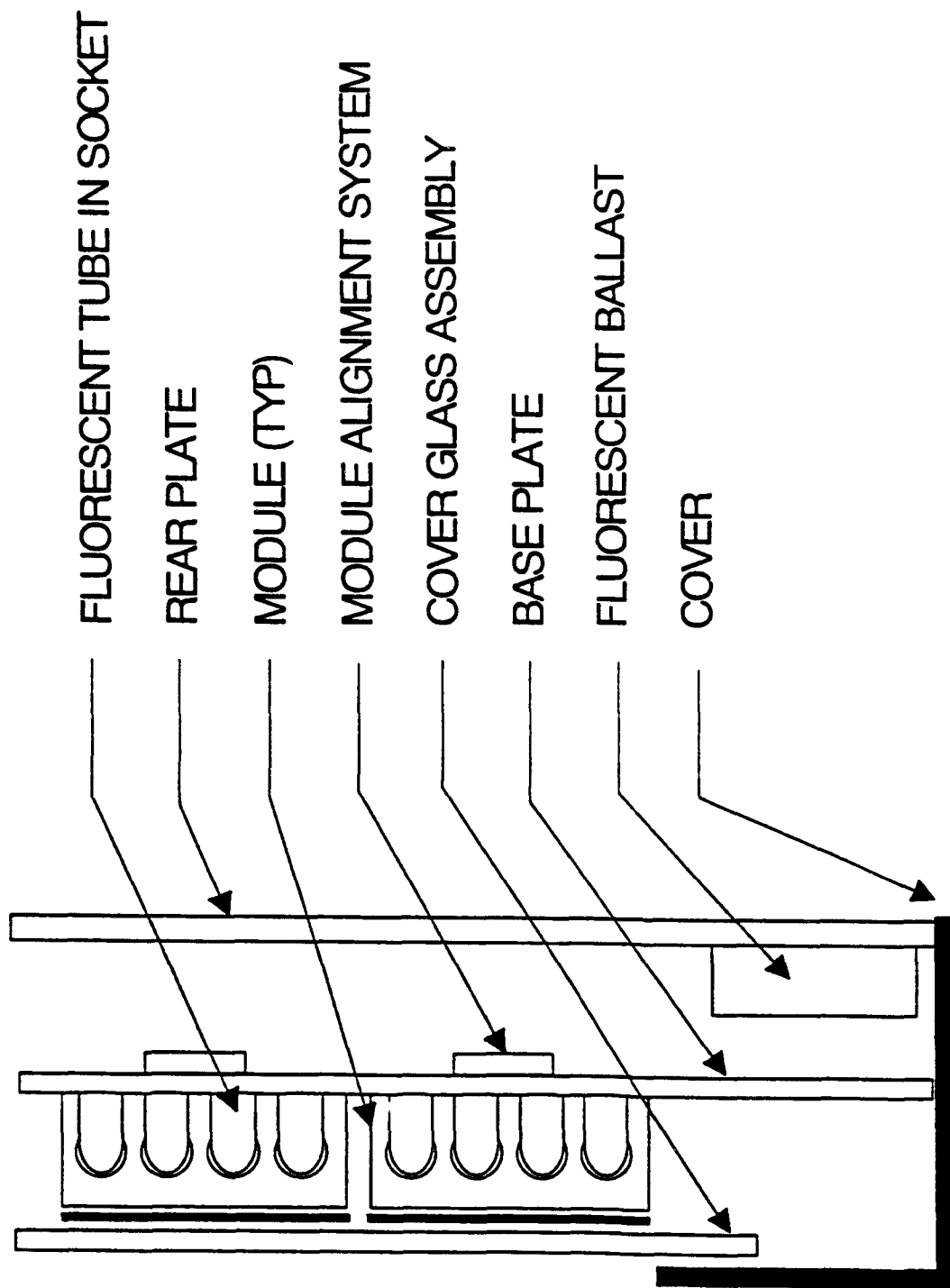
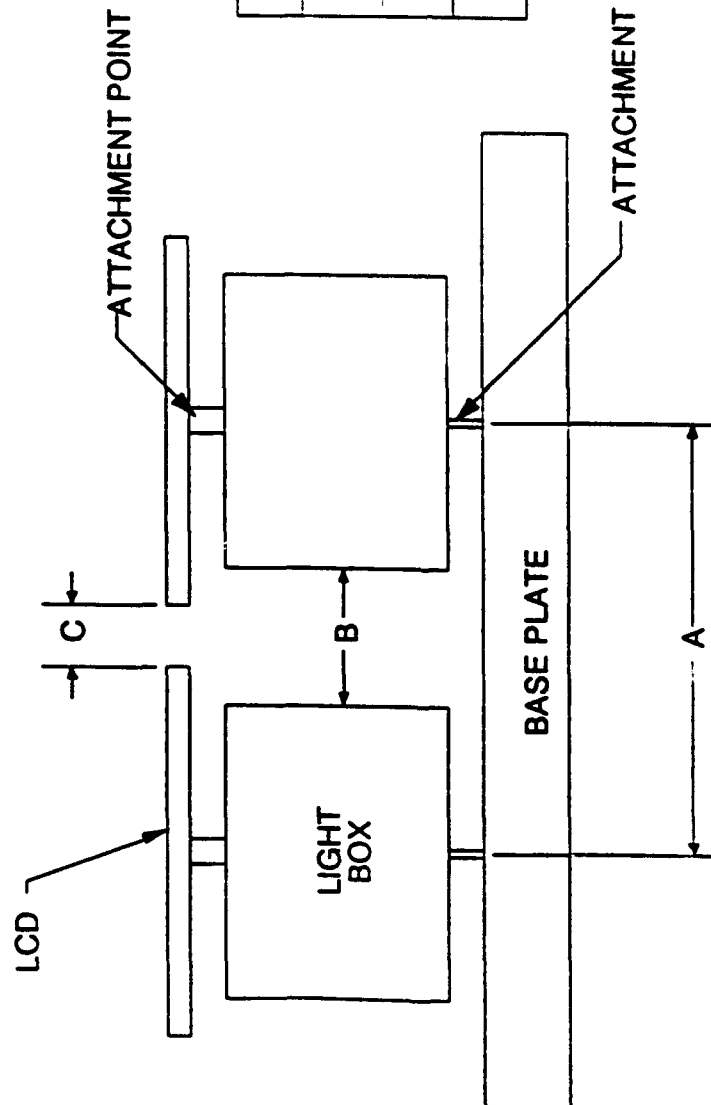


FIGURE 2.3-1: BASE PLATE SYSTEM DESIGN



MECHANICAL ANALYSIS
FOR
COMPONENT INTERFERENCE

TEMP	A mm (in)	B mm (in)	C mm (in)
10°C	130.12 (5.123)	0.389 (0.0153)	0.064 (0.0025)
25°C*	130.18 (5.125)	0.305 (0.0120)	0.102 (0.0040)
50°C	130.25 (5.128)	0.165 (0.0065)	0.165 (0.0065)

* GAPS SET DURING SYSTEM ALIGNMENT



FIGURE 2.3-2: CENTER POSITION CONCEPT

DEVELOPMENT OF A LARGE AREA, TILED, LIQUID CRYSTAL DISPLAY

- Precise registration of each tile is achieved by an "X Y" and rotational adjuster located at the center position of each tile on the base plate. This allows individual tiles to be registered to the global black mask.

Figure 2.3-3 illustrates the tile alignment method.

- Fluorescent lamp socket strips are mounted to the base plate. This provides precise positioning of the tubes relative to the tiles. Tile registration or backlighting is not affected by lamp replacement.
- The rear plate is mounted via standoffs to the base plate. The fluorescent ballasts and electronic power supplies mounted to the rear plate are effectively isolated from the tiles.
- The cover encloses the entire display assembly. Cooling fans at the sides of the cover force air along the tube running through the modules.

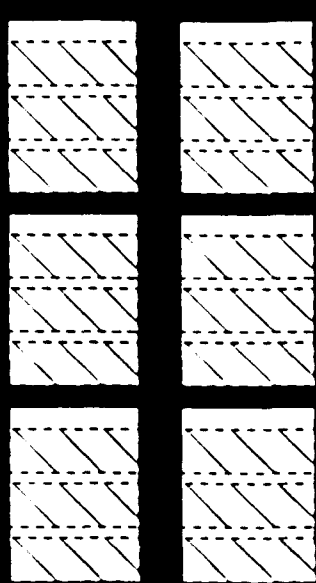
2.4 LCD MODULE DESIGN

The LCD modules are self contained, individually testable assemblies that consist of the following components:

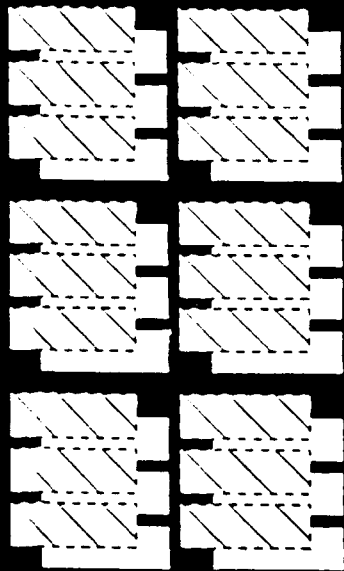
- TN LCD
- Light box and cover
- LCD driver printed wiring assembly (PWA)
- Flex circuits that interconnect the TN LCD to the driver PWA
- Color filter

A description of the module assembly follows:

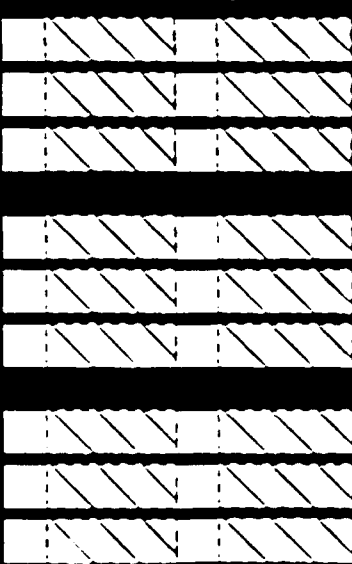
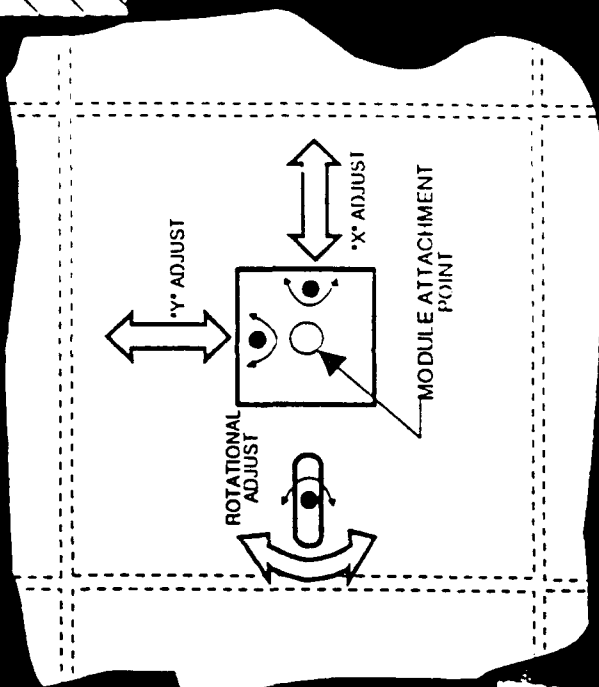
- The light box and cover are the core of the module assembly that support all other components. The rear of the light box also provides mounting points for securing the module to the base plate.
- The color filter is registered and laminated to the face of the LCD.
- The LCD is attached to the face of light box cover.
- The light box cover is precisely mounted to the front of light box. The light box and cover are dimensionally contained within the perimeter of the LCD.
- The driver PWA is mounted to the rear of the light box.



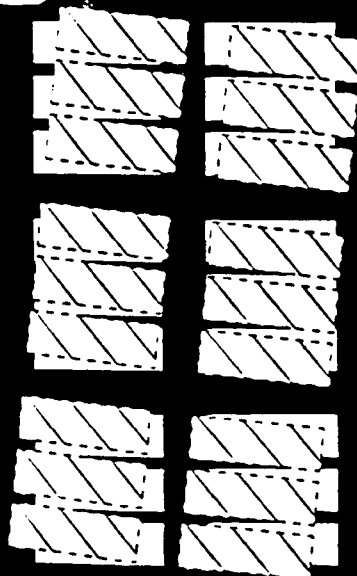
HORIZONTALLY



DIAGONALLY



VERTICALLY



SKEWED



MAGNASCREEN

FIGURE 2.3-3: LCD MODULE ALIGNMENT METHOD

DEVELOPMENT OF A LARGE AREA, TILED, LIQUID CRYSTAL DISPLAY

- Flex circuits span the four sides of the light box from the LCD edge connection to the driver PWA.
- Both the lightbox and row flexes provide access for fluorescent lamps to pass through.

Figure 2.4-1 illustrates the LCD module design.

2.5 BACKLIGHT DESIGN

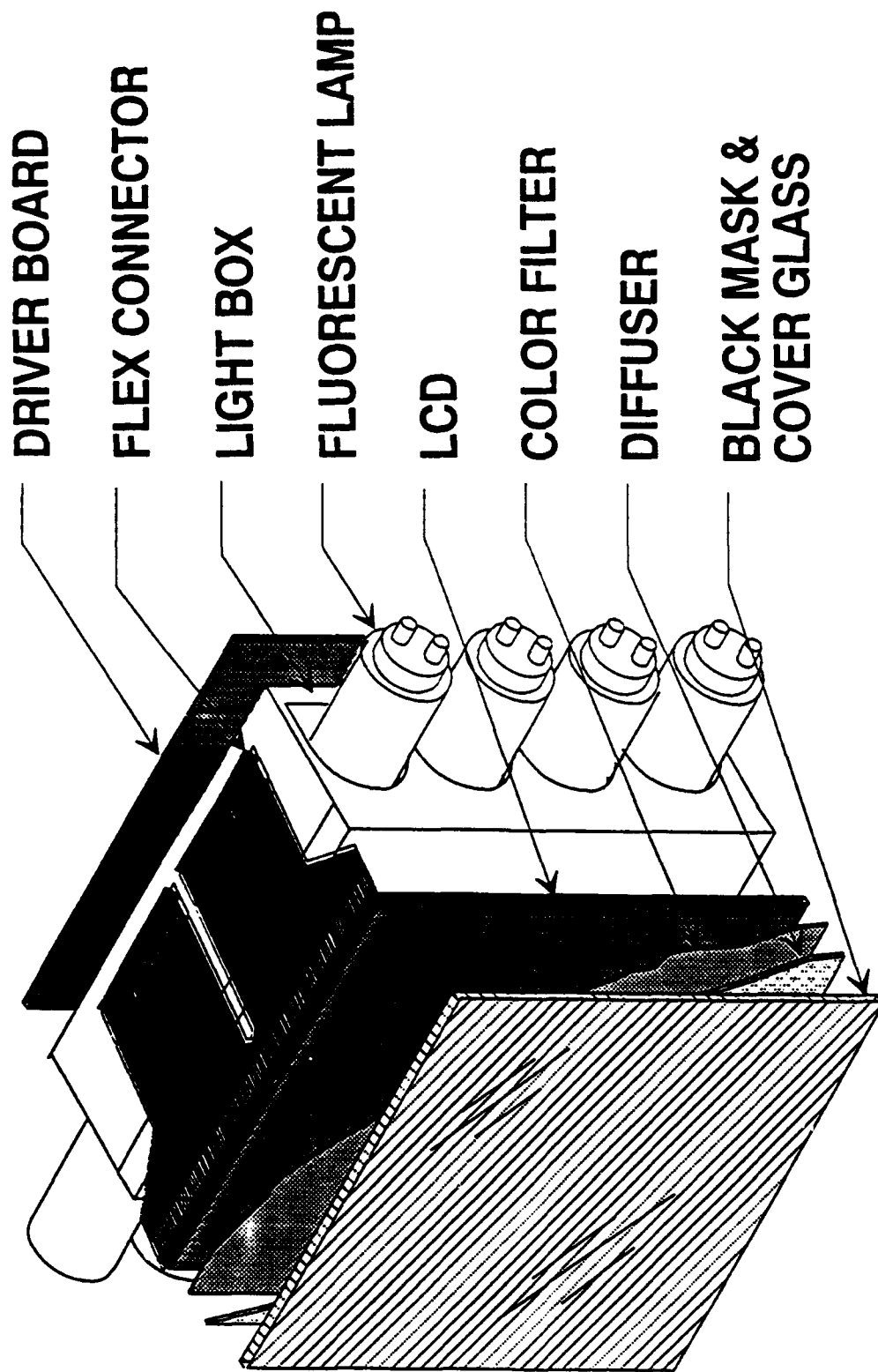
The backlight system design is based on an array of commercially available fluorescent lamps that create a global light source common to all the LCD modules in the display system. The backlight system design is specifically implemented as follows:

- A set of four (4) 2.54 cm (1") diameter fluorescent lamps run through each row of LCD modules.
- The lamp spacing and distance from the rear of the LCD is designed to maximize luminance and minimize luminance variation with only a thin diffusing layer between the light box cover and the LCD.
- The light box and cover combine the light output of the four (4) lamps to provide a diffuse light source behind each LCD.
- The multiple lamp design provides sufficient redundancy, so that the loss of one lamp does not significantly affect display readability.
- The edges of the light box and cover are shaped to maximize backlight uniformity to the edges of the LCD.
- The diffusing layer between the light box cover and LCD is designed to provide a variable transmission pattern, to inversely match any remaining lighting non-uniformities at the edges of the LCD.

Figure 2.4-1 also illustrates the backlight design.

2.6 OPTICAL DESIGN

The optical design provides the tiled display system with a seamless appearance while optimizing the tradeoffs between display contrast, luminance, color saturation, color purity, and viewing angle. The elements of the optical design include:



MAGNASCREEN

FIGURE 2.4-1: LCD MODULE/BACKLIGHT DESIGN

DEVELOPMENT OF A LARGE AREA, TILED, LIQUID CRYSTAL DISPLAY

- LCD optical characteristics
- Color filter
- Global black mask
- Global front diffuser

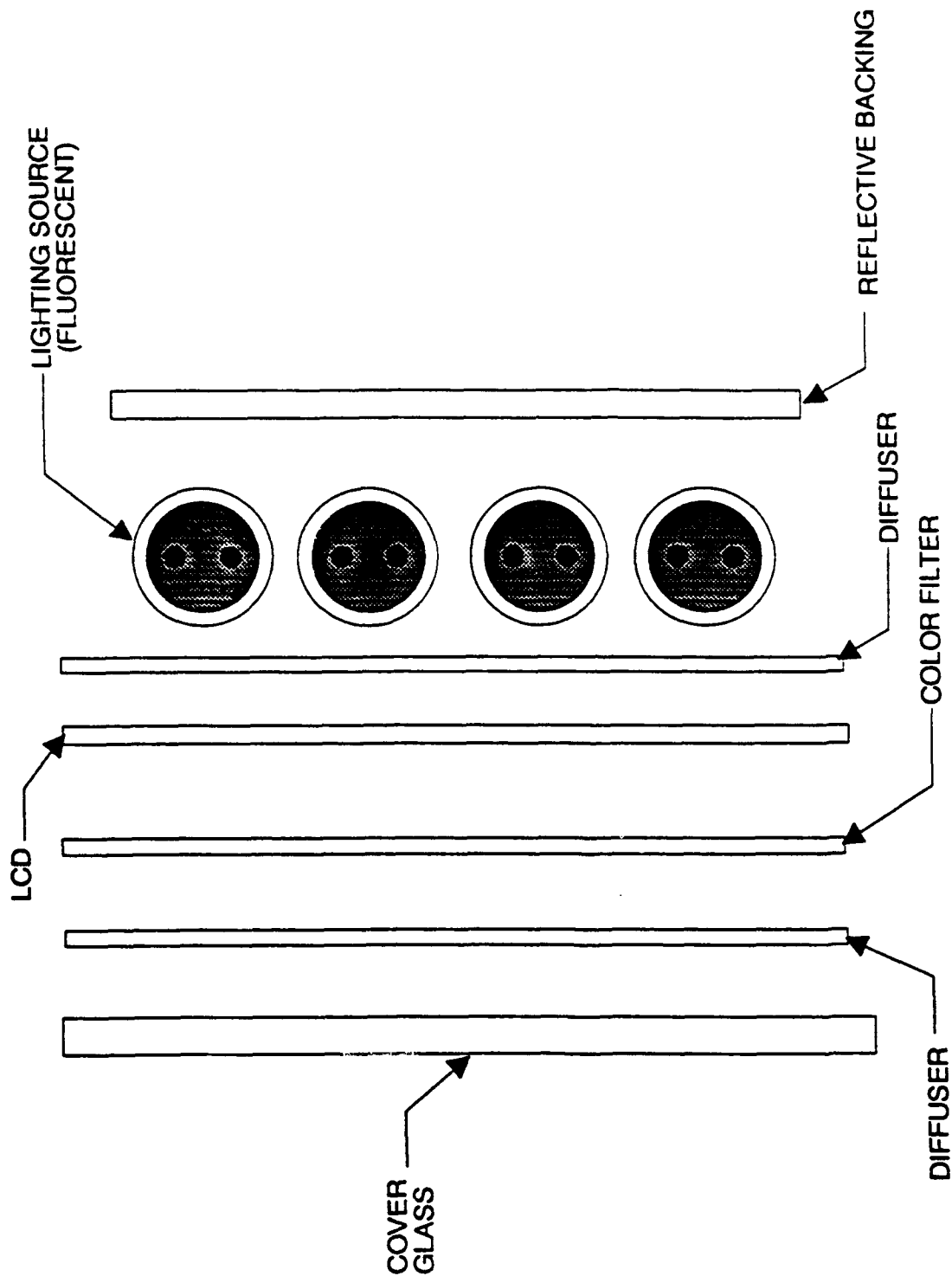
Figure 2.6-1 illustrates the stack-up of optical components.

The optical design is based on the following:

- The global black mask provides the same black stripe between all color pixels across the array of LCD modules. The mechanical seams between the adjacent tiles are therefore hidden by the black stripes providing a display mechanically seamless in appearance.
- The color filter and black mask are placed emulsion to emulsion to prevent color shifts over viewing angle due to parallax. To accomplish this the color filter is laminated to the front surface of the LCD.
- The monochrome LCD is designed with groups of pixels in triads. The monochrome triads correlate with RGB stripes that make up each color pixel on the color filter. The LCD pixels shutter the backlight illuminating the laminated color filter to create a color display.
- The size of the LCD pixel opening and the RGB stripes are designed to allow for light spreading and parallax due to the thickness of glass between the LC layer and the color filter.
- The LCD is configured in a normally dark mode to prevent light transmission between the LCD pixels, which would illuminate the color filter. Light transmitted between the LCD pixels reduces display color contrast, saturation and purity.
- The LCD is configured to maximize pixel contrast versus pixel transmission at the lowest off state transmission. This again maximizes color contrast, saturation and purity by minimizing light transmitted between color pixels and off pixels.
- The inherent viewing angle of the display is increased by the use of a global front diffuser that is designed to redistribute the light exiting the color filter over a wider angle. The amount of diffusion selected is based on finding the optimum compromise between display contrast, luminance and viewing angle.

2.7 ELECTRONIC DESIGN

The display system electronics are designed to be hardware and software compatible with existing computer systems. The electronic designs use "off the shelf" LCD controllers and LCD drivers configured to operate an array of individual tiles as one monolithic display. The main elements of the system electronic design are described in the following paragraphs:



MAGNASCREEN

FIGURE 2.6-1: STACK-UP OF OPTICAL COMPONENTS

DEVELOPMENT OF A LARGE AREA, TILED, LIQUID CRYSTAL DISPLAY

Figure 2.7-1 provides a block diagram of the display system electronics.

INTERFACE ELECTRONICS

The interface electronics, located in the display unit, were designed to appear as "virtual monolithic display" compatible, with standard high multiplex rate LCD controllers. The main function of the interface electronics is to take the high multiplex rate (480:1), and operate rows of LCD modules within the array at low multiplex rates (40:1). The design is implemented as follows:

- The standard controller (located in the host system) is presenting data to an alternating two (2) page RAM memory.
- The controller display data is written to one page of RAM memory, while the other page of RAM provides data for the sub-controllers that operate each row of LCD modules.
- Timing and control logic swaps the pages of RAM memory each frame. Therefore, as the last frame of data written to RAM memory by the controller is being displayed, the next frame of controller display data is being written to the other page of RAM memory. This RAM memory swapping operation is transparent to the controller.
- The transparent operation is designed to allow gray level encoding to pass through to the LCD modules.
- Each of the sub-controllers uses a selected portion of RAM memory that corresponds to the row of LCD modules within the display being driven. The sub-controllers operate each LCD module row in a two page 80 X 640 configuration.
- The timing, control and sub-controller functions are implemented in programmable logic arrays reducing the interface electronics design complexity and part count.
- A local processor is provided to allow for stand alone operation of self test and calibration functions. Fixed display patterns are available for optical and mechanical calibration and verification of interface electronic operation.

Figure 2.7-2 provides a block diagram of the interface electronics.

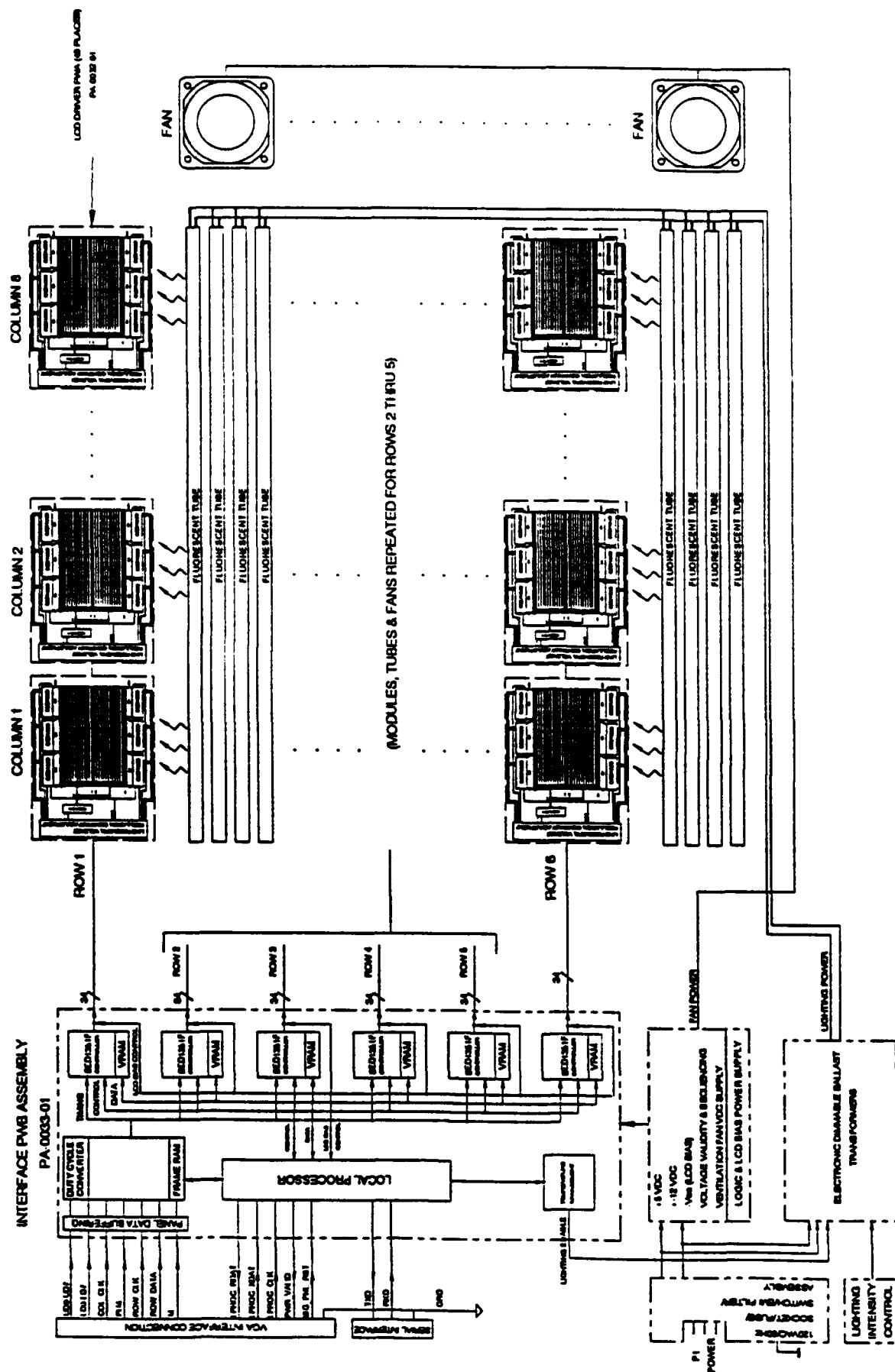


FIGURE 2.7-1: BLOCK DIAGRAM OF SYSTEM COMPONENTS

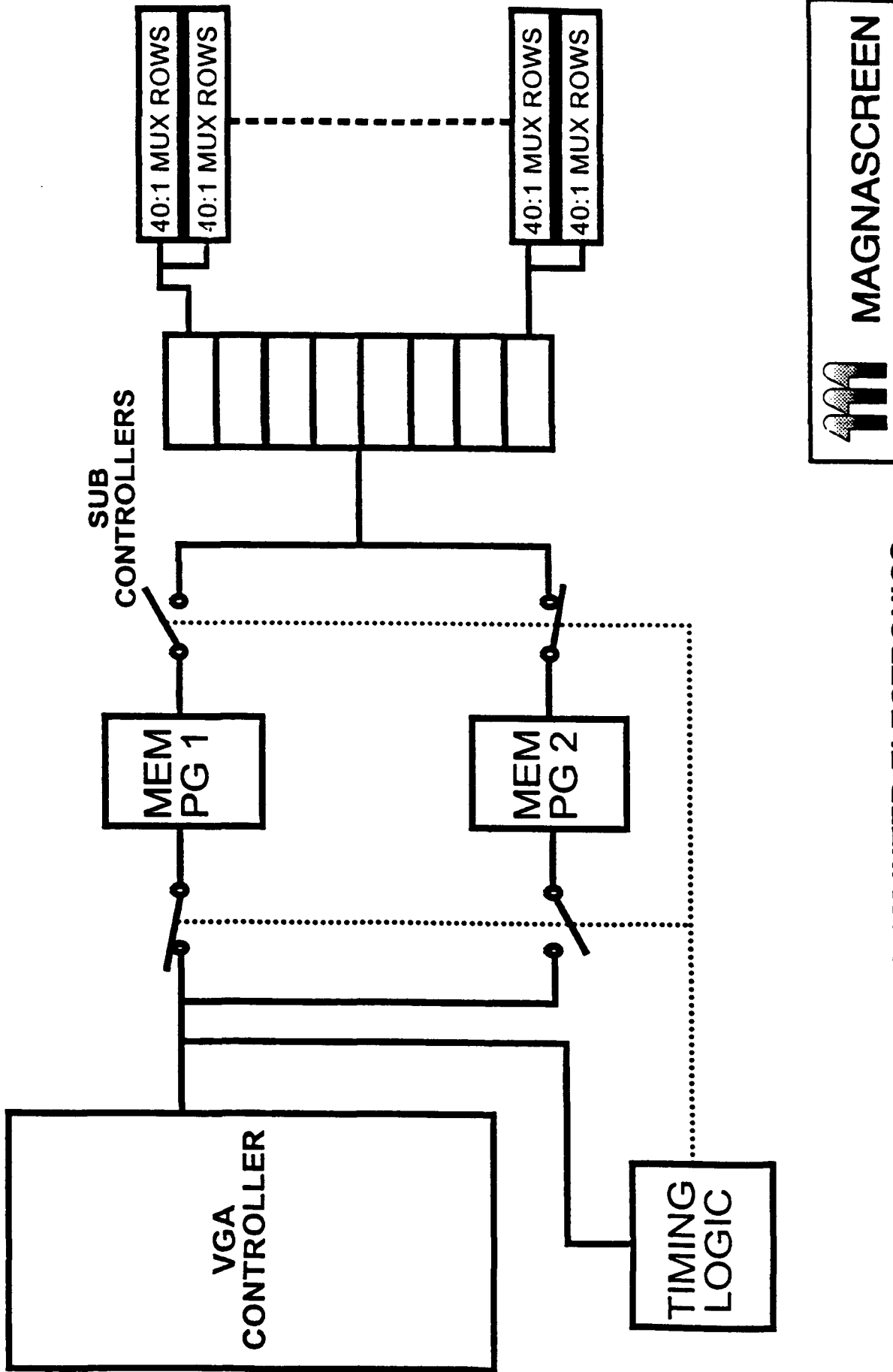


FIGURE 2.7-2: BLOCK DIAGRAM INTER-ELECTRONICS

DEVELOPMENT OF A LARGE AREA, TILED, LIQUID CRYSTAL DISPLAY

LCD DRIVER ELECTRONICS

The LCD driver electronics, located within each module, provides the following functions:

- 40 row driver outputs that drive the upper and lower 40 rows of the LCD in parallel.
- 480 column driver outputs that drive the upper 240 columns and lower 240 columns with independent data.
- "Daisy chain" input/output data paths to allow a row of modules to be operated from a single sub-controller.
- Generation of multiplex voltages from the +5 VDC logic and a single negative voltage supply.
- The ability to electronically control the LCD drive voltage remotely from the host computer. Individually addressable, digitally controlled potentiometers vary the amplitude of the negative voltage supply. This function allows the transmission versus contrast characteristic of each LCD to be varied for the purpose of optical matching of tiles within the array.

VGA CONTROLLER CARD

The standard VGA controller used to operate the tiled display system is a Cirrus Logic chipset GGD6410 and GD6340, designed for use with laptop computers using passive matrix displays. An ISA bus compatible VGA controller card design is located within the host computer. Line drivers are added to extend the cable length between the host computer and the display system up to 8M (25'). The VGA controller is software compatible with available application software packages.

POWER SUPPLIES

The display system contains power supplies that allow the unit to operate on 120VAC. The power supplies include:

- DC supplies to operate the system electronics.
- DC supplies to operate the cooling fans.
- Electronic fluorescent ballasts to operate the fluorescent lamps used for backlighting.

DEVELOPMENT OF A LARGE AREA, TILED, LIQUID CRYSTAL DISPLAY

3.0 SYSTEM PROTOTYPE RESULTS

The following sections detail the results of the tiled display system development including:

- A tiled display system technology demonstration via a display comprised of a 3 X 2 array of LCD modules.
- The detailed design and mechanical fabrication of a 1.3M (51") VGA display system product demonstration.

3.1 LCD PROTOTYPE FABRICATION

3.1.1 PROCESS DEVELOPMENT

Magnascreen developed and refined an LCD manufacturing process for fabricating the "thin seam" LCD s required to achieve a tiled display system, seamless in appearance. This included:

- The development of a "thin seal" process that consistently produces 0.13mm (0.005") epoxy seal width. The process was developed using a precision epoxy dispenser in conjunction with precision laminating and glass cutting techniques.
- The development of a precision glass and polarizer cutting process within a +/- 0.03mm (0.001") tolerance.
- The refinement of an "edge contact" process Magnascreen had previously demonstrated. The process was refined to produce high yielding, reliable edge contacts at densities of fifty (50) contacts per inch. The process required developing a multilayer thin film patterned electrode at the glass edges that provide a reliable contact area for sputtered thin film edge contacts. Sputter masks were developed to reliably deposit thin film edge contacts in precise alignment to the patterned electrodes.
- The refinement of the substrate lamination process to produce cell spacing uniformity to within one pixel from the edge of the active area. This required modifications to the epoxy lamination and fill station processes.
- The development of a color filter lamination process.

3.1.2 PROTOTYPE FABRICATION

The following summarizes Magnascreen's prototype fabrication effort during the program:

- Four (4) batches of LCD prototypes were started during the program for assembly into LCD modules.
- Each batch consisted of between 60-80 substrate starts.

DEVELOPMENT OF A LARGE AREA, TILED, LIQUID CRYSTAL DISPLAY

- These starts yielded a total of approximately 40 displays that were mechanically, electrically and optically useful for assembly into LCD modules.
- Corrective actions to the process were implemented between batches. The corrective actions on the initial batches concentrated on thin seal and edge contact process refinement. The later batches concentrated on cell uniformity and optical performance affecting seamless appearance.

Table 3.1.2-1 summarizes the batch process yield result and the predicted achievable yields.

3.1.3 REMAINING LCD PROCESS DEVELOPMENT AND FABRICATION ISSUES

Remaining LCD process development and fabrication issues include:

- Refinement of the fill hole epoxy sealing process to prevent light leaks.
- Refinement of the color filter lamination and registration process.
- Refinement of the alignment layer buff direction and polarizer alignment process to improve cell to cell optical uniformity.

3.2 MECHANICAL ASSEMBLY

The results of fabricating both the 3 X 2 LCD module array and the 1.3M (51") mechanical assemblies indicated the following:

- The base plate mechanical design concept performs the design functions required to create a mechanically seamless array of LCD modules. The requirement to accurately position LCD modules within 0.05mm (.002") was demonstrated.
- The base plate design is easily scaleable to accommodate other LCD module array configurations. Scaling up from the 3 X 2 array to the 8 X 6 array required for the 1.3M (51") VGA display was readily accomplished. The base plate fabrication tolerances were kept well within CNC machining capability. It was demonstrated that base plate components for larger arrays of LCD modules can be assembled from a set of smaller, easier to manufacture components.
- The "X Y" and rotational adjusters need further refinement. The range and smoothness of movement can be improved by minor modifications to adjuster components. The rotational adjustment was not implemented on the prototypes built to date. The necessity for rotational adjustment versus the added mechanical complexity to the adjusters was to be determined. Evaluations, at present, do not support the need for adding rotational adjustment. The need for a better locking mechanism to hold the module position once adjusted is required.

**DEVELOPMENT OF A LARGE AREA,
TILED, LIQUID CRYSTAL DISPLAY**

TABLE 3.1.2-1

BATCH PROCESS YIELD RESULTS

PROCESS STEP	BATCH 1 (%)	BATCH 2 (%)	BATCH 3 (%)	BATCH 4 (%)	PROJECTED (%)
Photolith	94	95	95	95	98
Alignment & Buff	97	97	86	98	99
Seal & Lamination	75	80	82	80	92
Fill	75	80	83	83	91
Glass Cut	20	40	55	72	90
Edge Contact	20	45	70	83	93
Flexing	80	82	83	78	97
Color Filter	80	85	86	72	98
Overall Yield	1.3	7.4	15.3	20.7	64.6

DEVELOPMENT OF A LARGE AREA, TILED, LIQUID CRYSTAL DISPLAY

- A better method to initially position the bezel containing the black mask to the array of modules is required. A registration system that places the black mask within the adjustment range of the modules would significantly reduce adjustment effort.
- More user friendly lamp socketing should be developed for future products to facilitate installation and replacement of the backlighting.
- Figure 3.2-1 provides a photograph of the active 3 x 2 unit fabricated.

3.3 LCD MODULE ASSEMBLY

The results of fabricating approximately forty (40) LCD module assemblies indicated the following:

- The LCD module design meets the mechanical functions relative to alignment and individual replaceability. The mechanical tolerances must be refined to take into account squareness and edge smoothness of the mechanical components. Mechanical interference between adjacent LCD modules interfered with alignment of the LCD modules to the global black mask.
- Assembly of the LCD modules was straight forward with minimum difficulty. The basic assembly procedure included:
 - Flexes were attached to the LCDs prior to assembly of the LCD module.
 - The light box and cover are painted for optical purposes and assembled.
 - The driver PCB is mounted to the rear of the light box.
 - The LCD and diffuser are mounted on the light box cover.
 - The flexes are wrapped around the light box, the conductive traces are aligned (via microscope) to the driver PCB contact pads, tacked in place.
 - The LCD module is placed in a fixture where heat and pressure are applied to complete the lamination of the flex conductors.
- The process for optically attaching the LCD to the light box cover must still be developed.
- A more time efficient method of initially aligning and tacking the flexes to the driver PCB must be developed.
- Figure 3.3-1 provides a photograph of the LCD module and assembly fixture.

3.4 BACKLIGHT ASSEMBLY

Evaluations of the backlight assembly provided the following results:

*DEVELOPMENT OF A LARGE AREA,
TILED, LIQUID CRYSTAL DISPLAY*

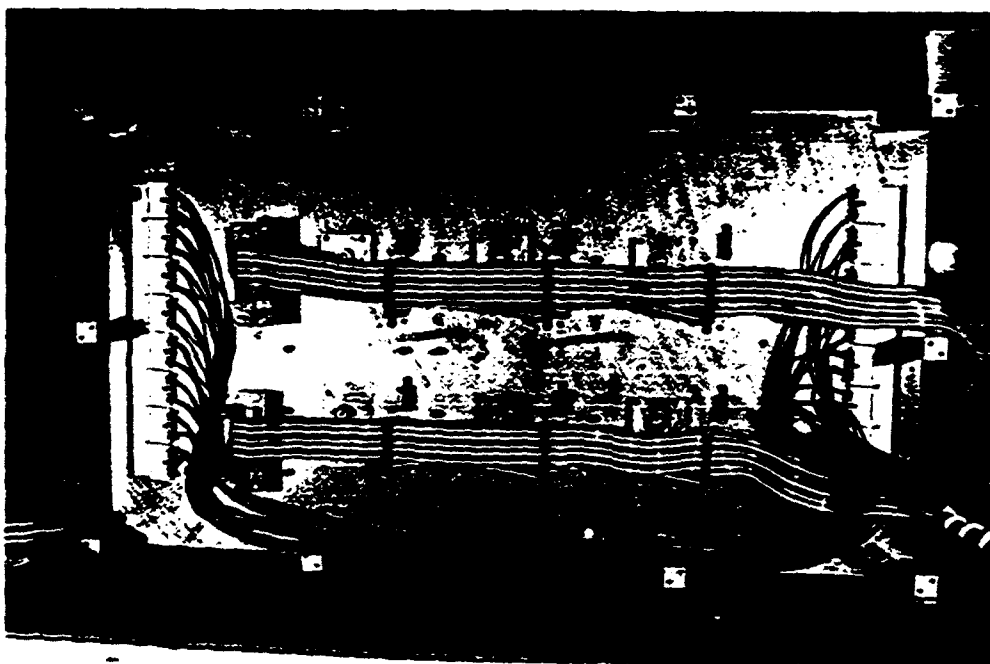
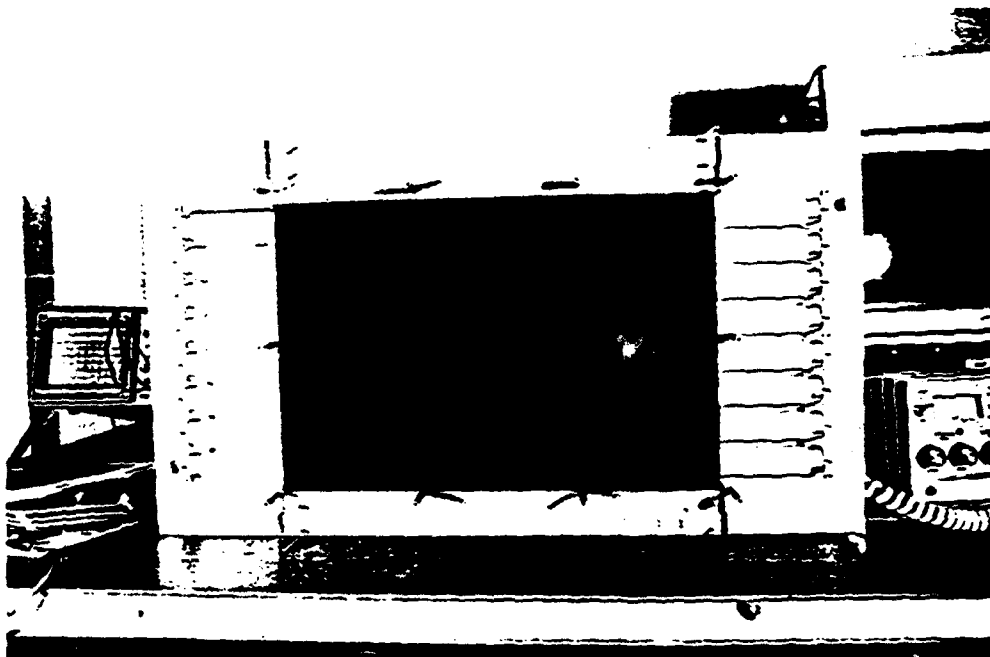


FIGURE 3.2-1

3 x 2 UNIT BASE PLATE PHOTOGRAPHS

***DEVELOPMENT OF A LARGE AREA,
TILED, LIQUID CRYSTAL DISPLAY***

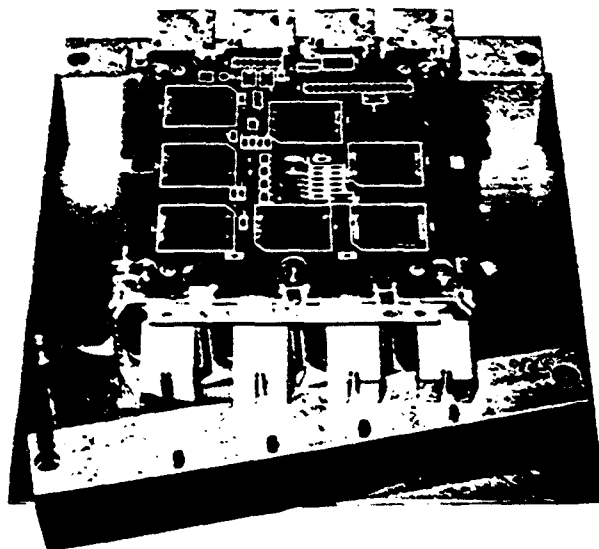


FIGURE 3.3-1

TILE ASSEMBLY FIXTURE PHOTOGRAPH

DEVELOPMENT OF A LARGE AREA, TILED, LIQUID CRYSTAL DISPLAY

BACKLIGHT LUMINANCE

- The fluorescent lamps (commercial type:F17/T8) within each light box provide an average of 1200 lumens in an area of 168 cm^2 (26 square inches). This provided a theoretical maximum light box luminance of $23,000 \text{ candela/m}^2$ (6650 fL).
- The average measured luminance at the surface of the light box cover in the 3 X 2 unit prior to diffusion was $17,130 \text{ candela/m}^2$ (5000 fL).
- A 0.13mm (0.005") thick mylar diffuser was added to maximize light box cover surface uniformity. The average measured luminance of the light box cover in the 3 X 2 unit after diffusion was $12,100 \text{ candela/m}^2$ (3500 fL).

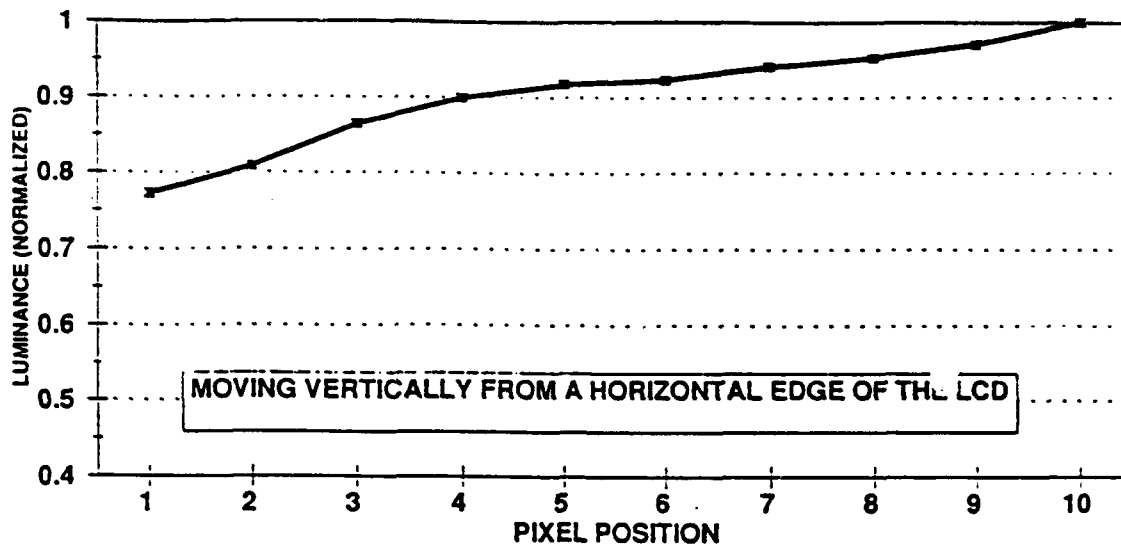
BACKLIGHT UNIFORMITY

- The uniformity of the light box and cover was determined out to the edges. The measurements indicated a fall off of luminance at the edges of the light box cover.

Figure 3.4-1 provides a graph of the measurements for both the horizontal and vertical edges.

- The causes of the falloff were found to be:
 - Insufficient light piping in the walls of the light box to properly illuminate the edge of the light box cover
 - Light box cover horizontal edge shaping required further refinement to redistribute light out to the edge.

UNIFORMITY OF LUMINANCE AT THE HORIZONTAL EDGE OF LCD



NEW LIGHT BOX, NEW COVER, MODIFIED MYLAR DIFFUSER

LUMINANCE MEASUREMENTS AT COLUMN 40, PIXEL 1 IS THE PIXEL NEAREST THE EDGE

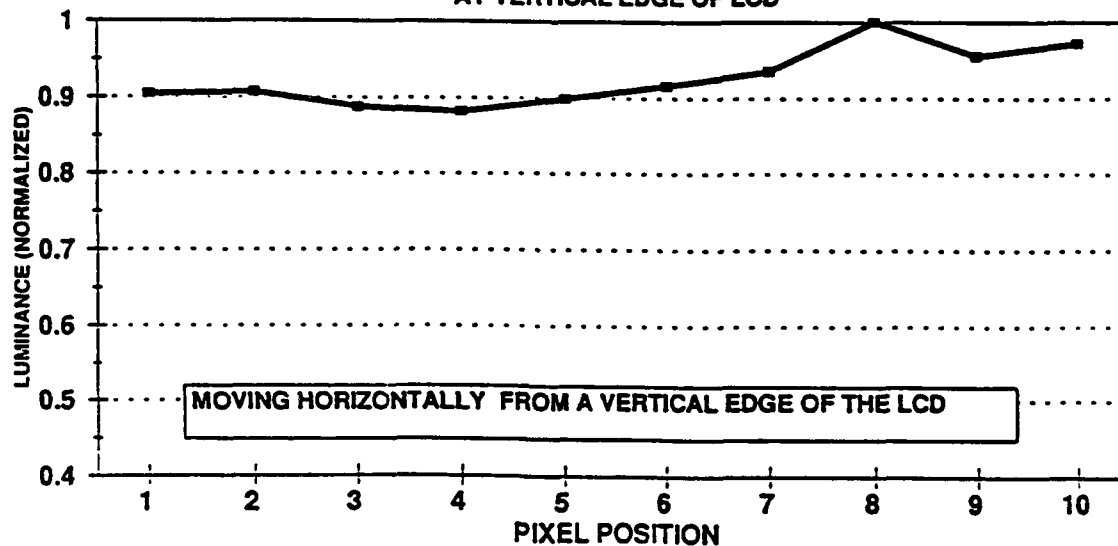
VERTICAL SCAN IS FROM PIXEL 1 TO PIXEL 10

LUMINANCE VALUES HAVE BEEN NORMALIZED

DISD75\DISUNF07.WB1

Figure 3.4-4A

UNIFORMITY OF LUMINANCE AT VERTICAL EDGE OF LCD



NEW LIGHT BOX, NEW COVER, MODIFIED MYLAR DIFFUSER

LUMINANCE MEASUREMENTS AT ROW 20, PIXEL 1 IS THE PIXEL NEAREST THE EDGE

HORIZONTAL SCAN IS FROM PIXEL 1 TO PIXEL 10

LUMINANCE VALUES HAVE BEEN NORMALIZED

DISD78\DISUNF07.WB1

Figure 3.4-4b

DEVELOPMENT OF A LARGE AREA, TILED, LIQUID CRYSTAL DISPLAY

- Corrective actions developed included:
 - Paint light box walls on the outside instead of the inside. This required modifying the dimensions of the light box and cover to compensate for the thickness of paint.
 - Modification to the shape of the existing light box cover horizontal edge. Further refinements to the light box cover are anticipated when the next batch of covers are fabricated.

Figure 3.4-2 illustrates the required light box cover modifications.

- Development of a patterned diffuser to compensate for any remaining non-uniformities. The patterned diffuser implemented was based on varying diffuser transmission by patterning black laser printed dots on the mylar diffuser. The pattern was based on the average transmission variation of a number of measured modules and results in about a 15% loss in display intensity. Improved uniformity and efficiency can be achieved with patterns customized to the transmission variation of individual LCD modules, and the development of a diffuser which varies diffuser transmission by patterning white dots on a clear media .

Figure 3.4-3 illustrates the patterned diffuser design.

Figure 3.4-4 provides a graph of the lighting uniformity measurements taken on both the horizontal and vertical edges after the corrective actions were implemented.

BACKLIGHT SYSTEM THERMAL CHARACTERISTICS

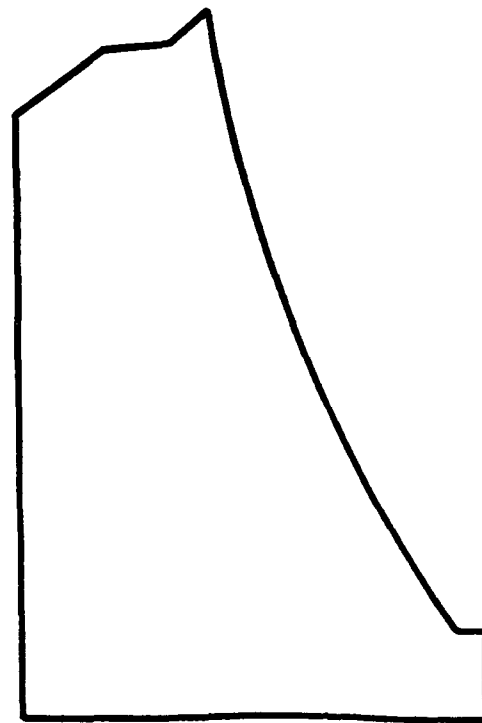
The heat rise of the backlight system was evaluated by measuring the temperature at the rear surface of each light box cover in the 3 X 2 unit.

Figure 3.4-5 provides a graph of the measured fan cooling effectiveness at two fan volumes.

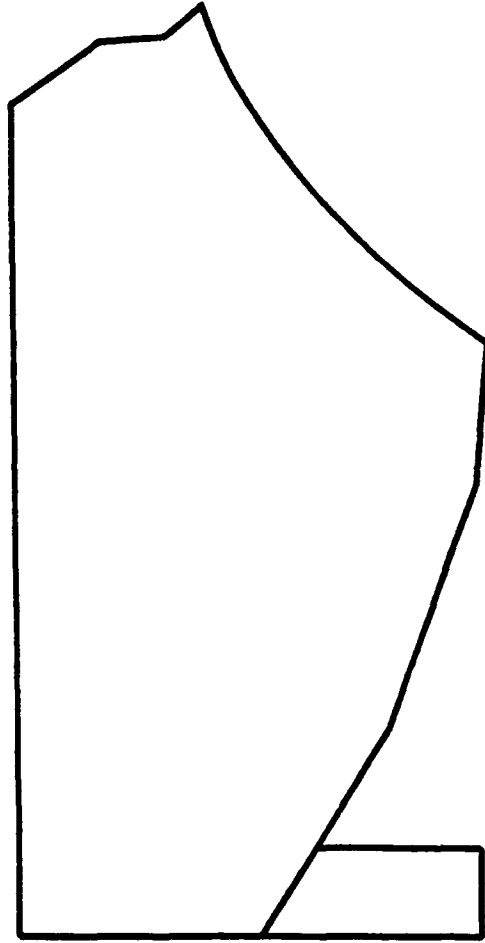
Figure 3.4-6 and Figure 3.4-7 provide graphs of the heat rise within the individual modules in the 3 X 2 unit.

The results of the measurements indicate that restrictions in the airflow through the modules were limiting the effectiveness of the fans. Modifications to increase the size of the lamp openings in the light box are required to reduce the total fan capacity required to maintain an acceptable heat rise.

Figure 3.4-8 provides a photograph of the 3 x 2 unit's backlight system.



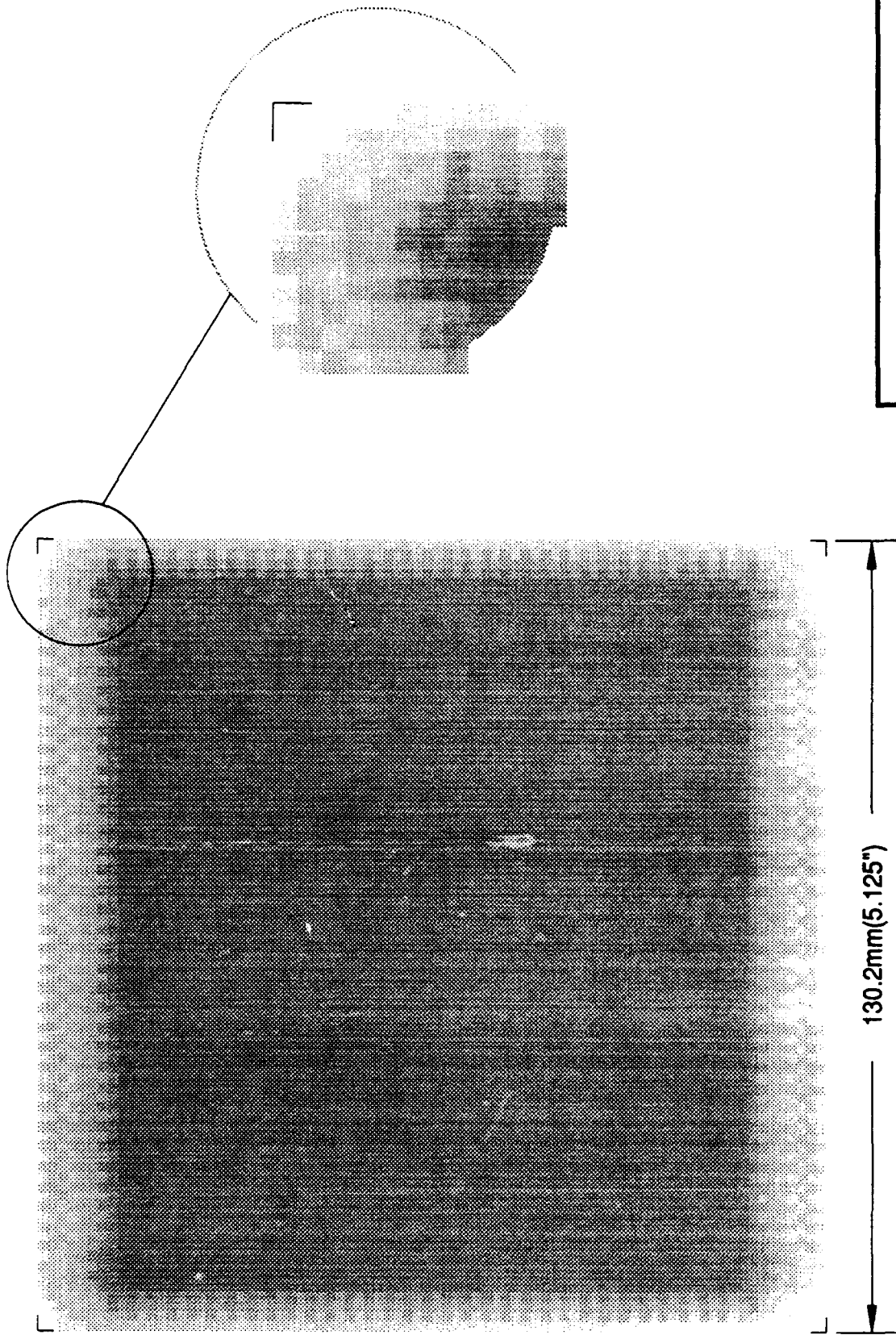
ORIGINAL DESIGN



IMPROVED DESIGN



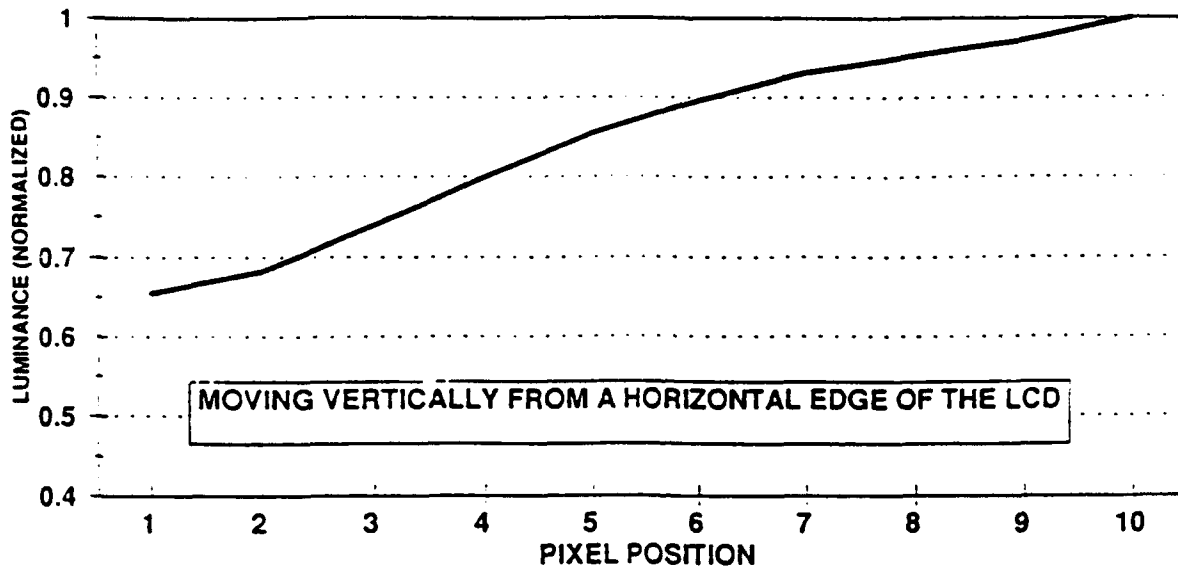
FIGURE 3.4-2: LIGHT BOX COVER MODIFICATION



 MAGNASCREEN

FIGURE 3.4-3 PATTERNED DIFFUSER DESIGN

UNIFORMITY OF LUMINANCE AT THE HORIZONTAL EDGE OF LCD

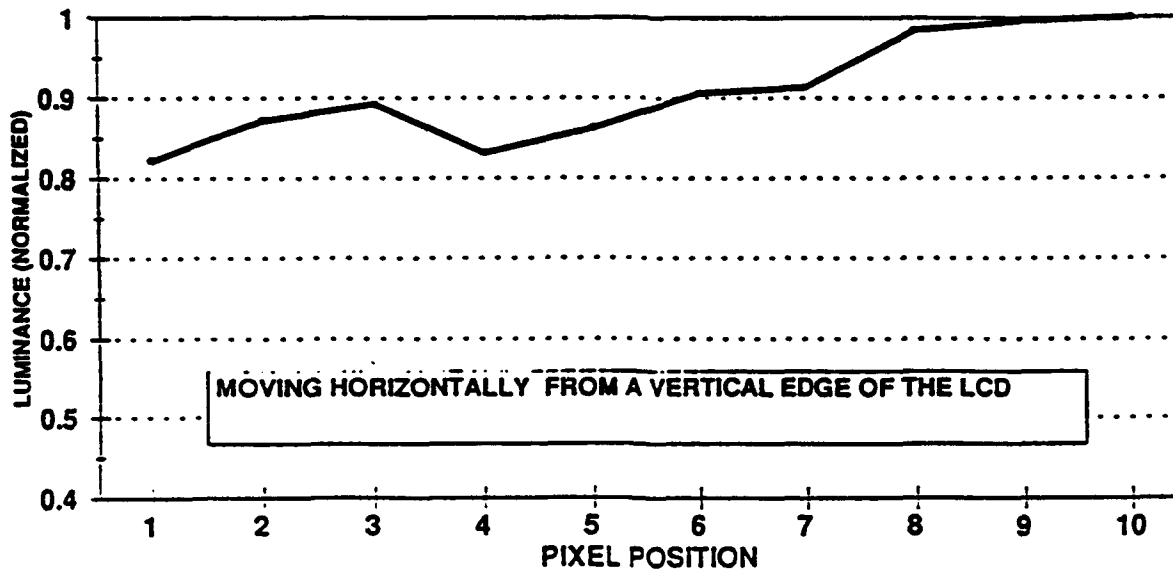


ORIGINAL LIGHT BOX, ORIGINAL LIGHT BOX COVER, AND ORIGINAL MYLAR DIFFUSER
 LUMINANCE MEASUREMENTS AT COLUMN 40, PIXEL 1 IS THE PIXEL NEAREST THE EDGE
 VERTICAL SCAN IS FROM PIXEL 1 TO PIXEL 10
 LUMINANCE VALUES HAVE BEEN NORMALIZED

DISD76DISUNF07.WB1

Figure 3.4-1A

UNIFORMITY OF LUMINANCE AT VERTICAL EDGE OF LCD



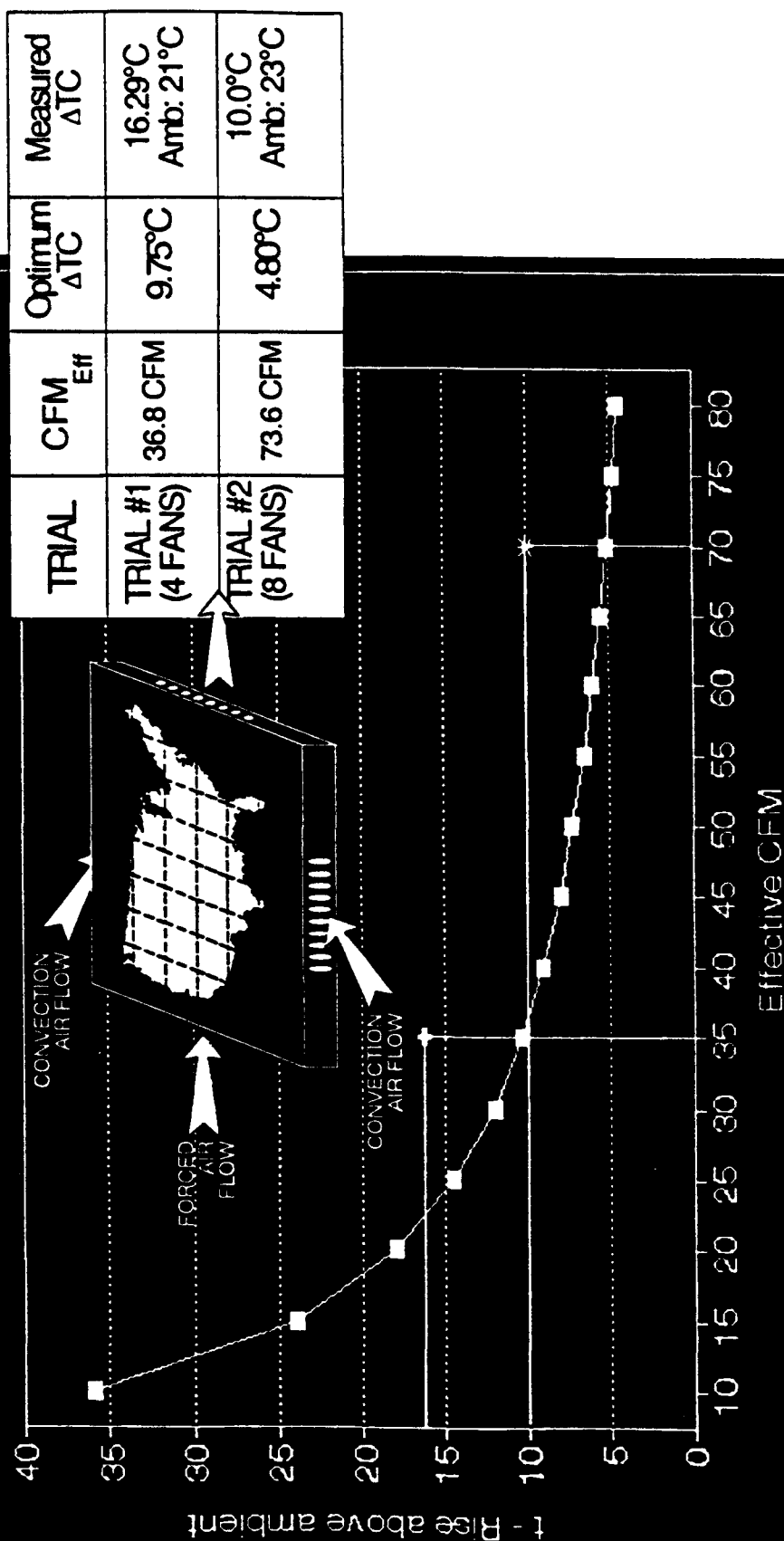
ORIGINAL LIGHT BOX, ORIGINAL LIGHT BOX COVER, AND ORIGINAL MYLAR DIFFUSER
 LUMINANCE MEASUREMENTS AT ROW 20, PIXEL 1 IS NEAREST THE EDGE
 HORIZONTAL SCAN IS FROM PIXEL 1 TO PIXEL 10
 LUMINANCE VALUES HAVE BEEN NORMALIZED

DISD77DISUNF07.WB1

Figure 3.4-1B

3 x 2 Tiled LCD display

Fan Cooling Analysis



MAGNASCREEN

FIGURE 3.4-5: MEASUREMENTS OF FAN COOLING EFFECTIVENESS

3x2 Tiled Display, 4-DEC-92

Fans: 4 out @12.0 Vdc

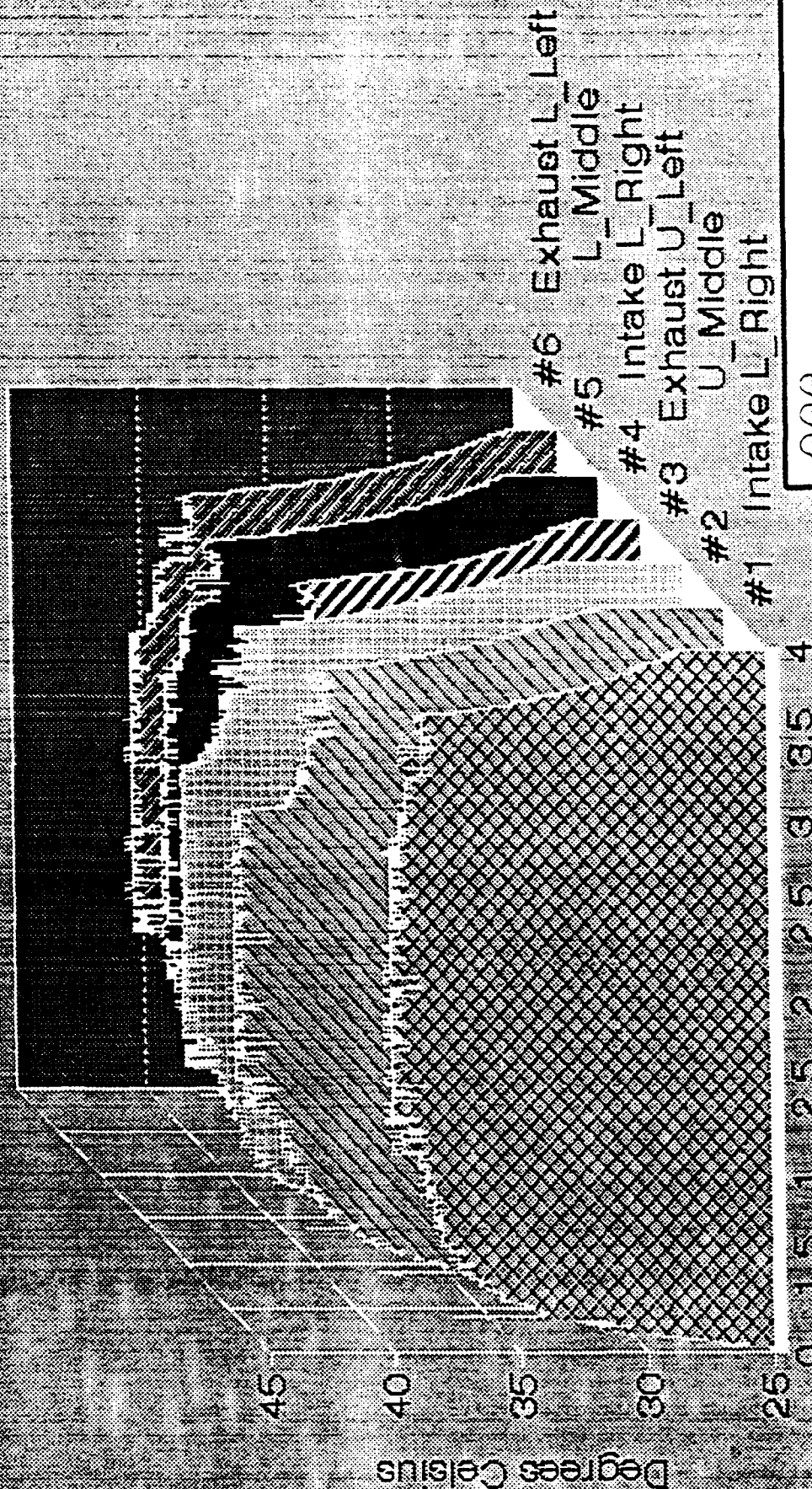


FIGURE 3.4-6: HEAT RISE WITHIN MODULES

3x2 Tiled Display, 8-DEC-92

Fans: 4in/4out @12.0Vdc

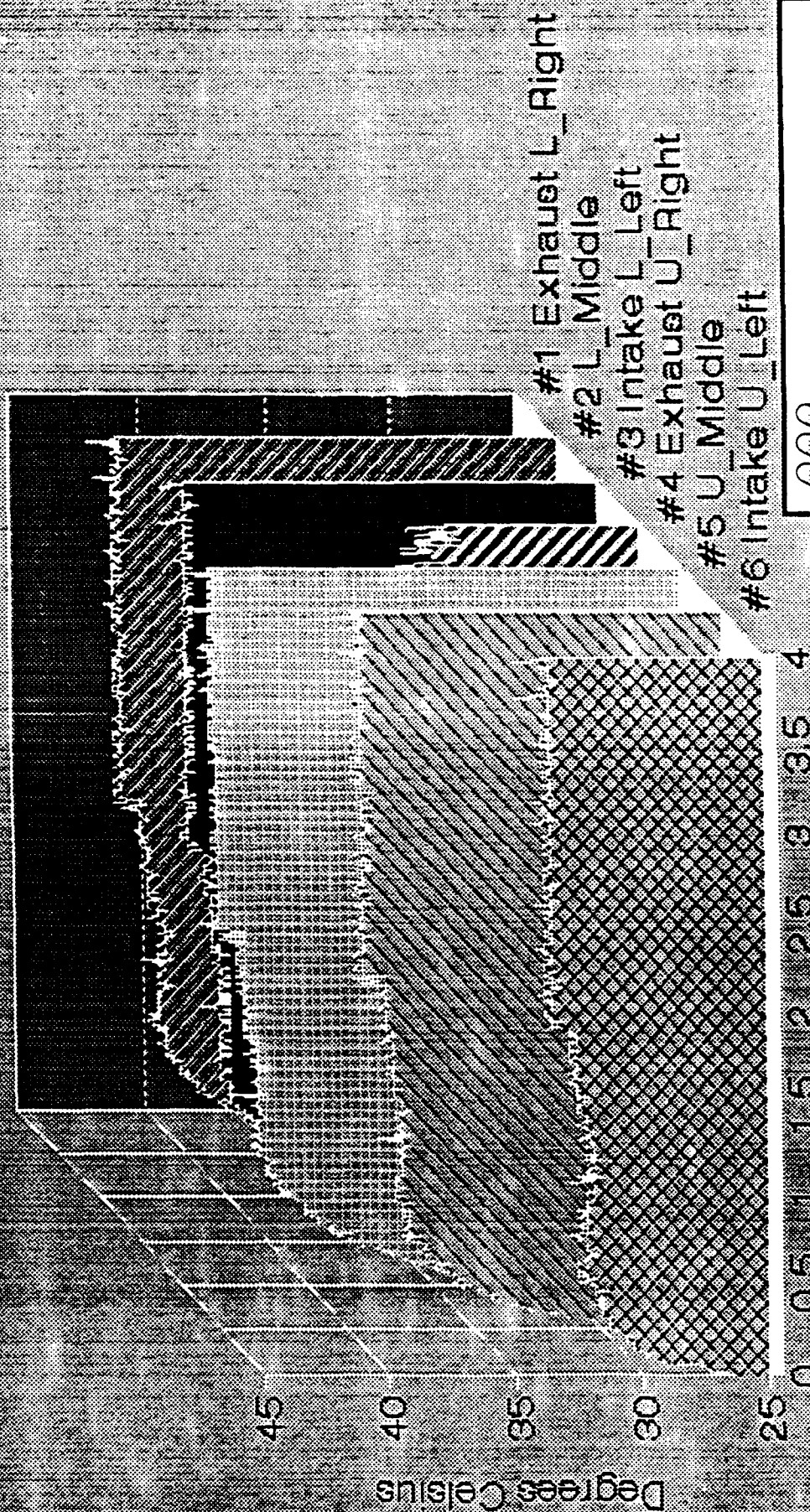


FIGURE 3.4-7: HEAT RISE WITHIN MODULE

***DEVELOPMENT OF A LARGE AREA,
TILED, LIQUID CRYSTAL DISPLAY***

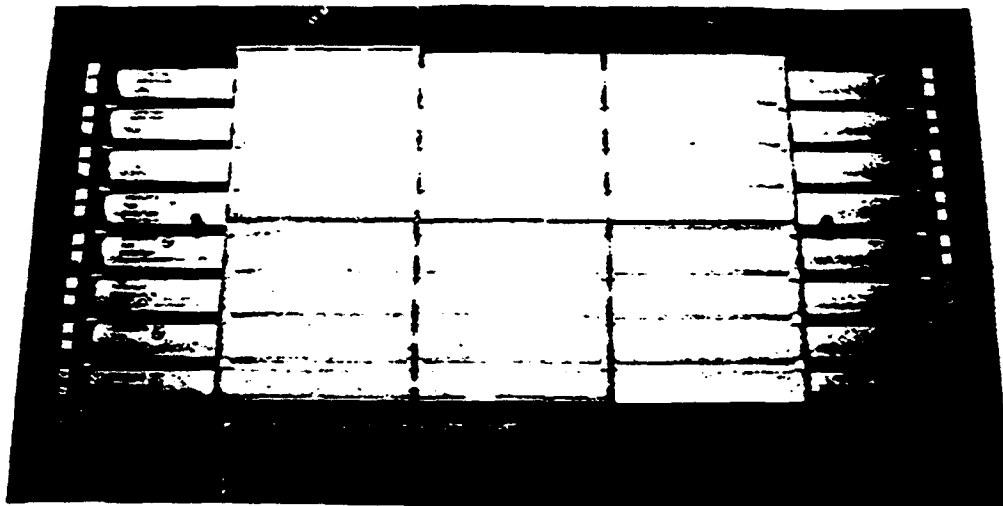


FIGURE 3.4-8

3 X 2 UNIT BACKLIGHT SYSTEM PHOTOGRAPH

DEVELOPMENT OF A LARGE AREA, TILED, LIQUID CRYSTAL DISPLAY

3.5 COLOR FILTERS

The color filter technology developed during this program included:

- "Cromalin" color filters fabricated by a pre-print process using available printing industry Pantone® colors.
- Color filters fabricated by standard offset printing process.

The results of using these color filters on the prototype tiles indicated:

- The front laminated color filter design creates the desired color display.
- The predicted light spread between the LCD and color filter pixel was less than anticipated. This indicates the size of the LCD pixel can be increased. This should increase the overall intensity of the display system.
- The "cromalin" filters did not have sufficient color saturation, but provided good color uniformity. Improved color saturation and added resistance to potential damage during the lamination process is required if these color filters are to be used as part of the final product.
- The initial subjective evaluation of the printed color filters was positive. Further evaluation for mechanical integrity, color registration and color consistency, is required.

3.6 OPTICAL PERFORMANCE

The optical performance of the display system was evaluated in two main areas:

- The display's seamless appearance was evaluated by trying to correlate observed seams with measurable optical parameters.
- LCD optical parameters were measured to provide a base line for future developments.

3.6.1 SEAMLESS APPEARANCE

The 3 x 2 unit clearly demonstrated the feasibility of making a tiled display system seamless in appearance at moderate resolutions (16 lpi) with the system design approach developed.

The 3 X 2 unit demonstrates both vertical and horizontal seams that are not visible to the eye at the intended viewing distance of > 4m (12 feet).

Figures 3.6.1-1 through 3.6.1-4 provide photographs of various graphic images displayed on the 3 X 2 unit. Photographs are taken from a distance of 4m (12 feet).

DEVELOPMENT OF A LARGE AREA, TILED, LIQUID CRYSTAL DISPLAY

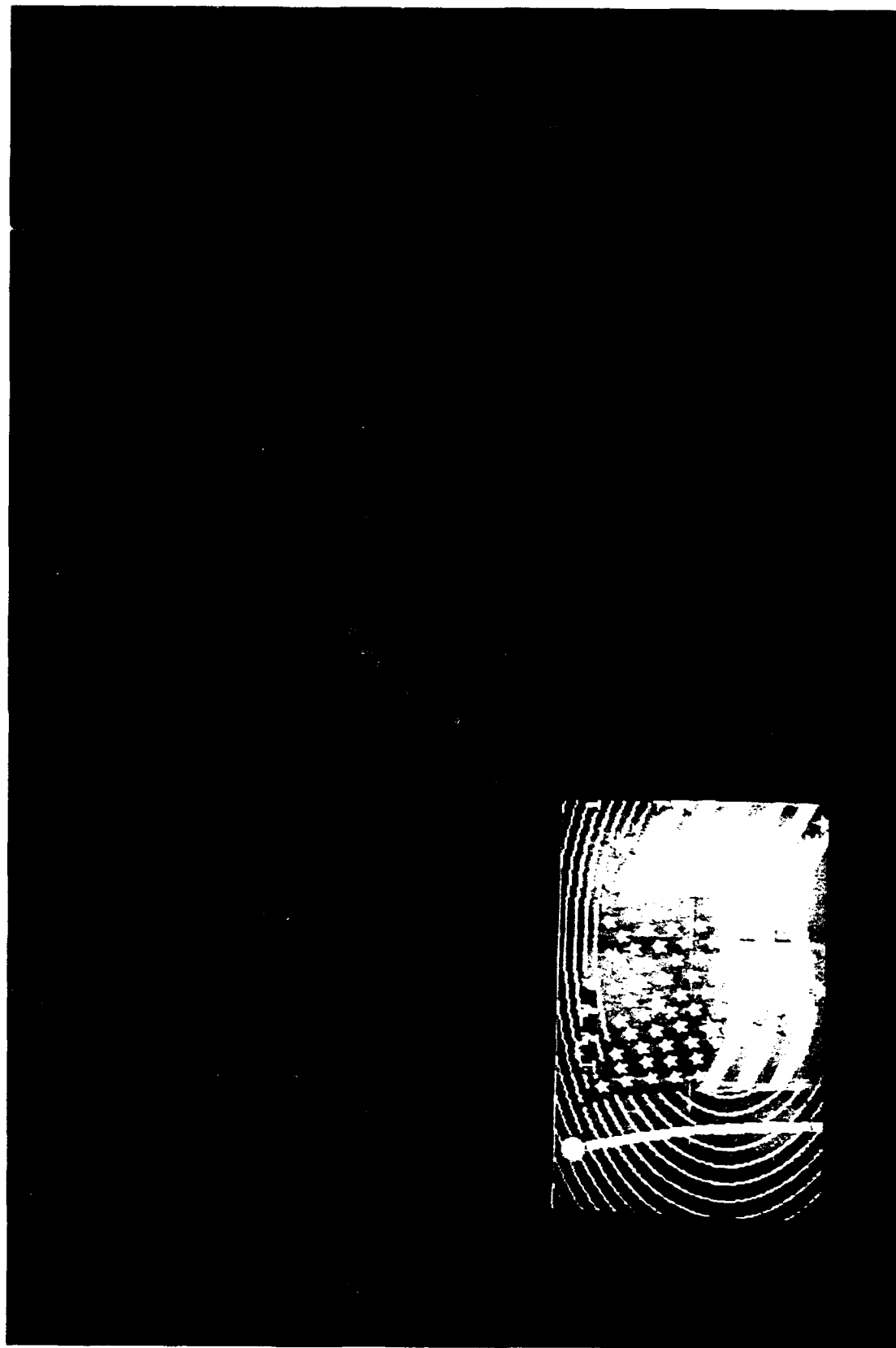
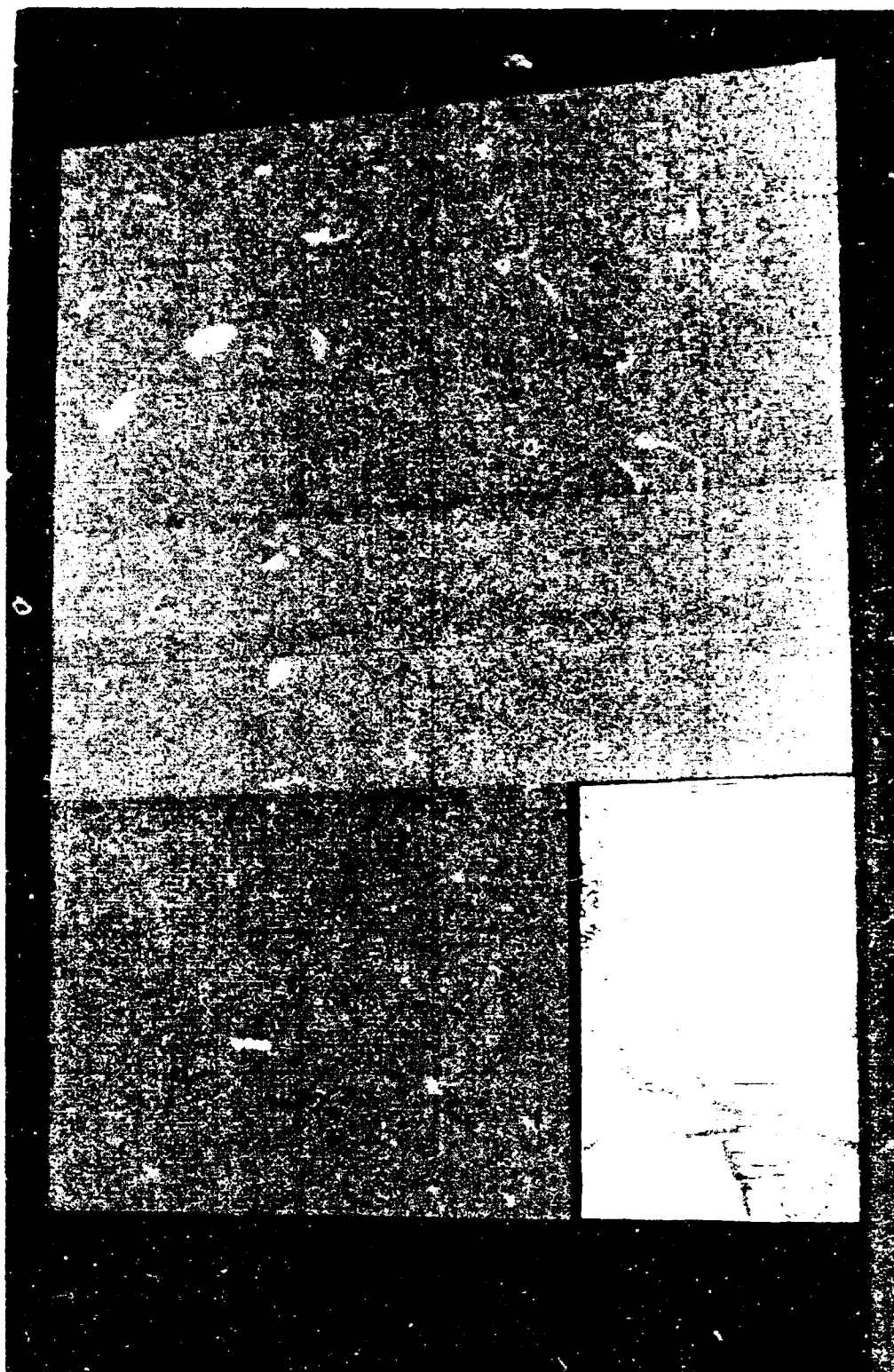


FIGURE 3.6.1-1

PHOTOGRAPH OF GRAPHIC IMAGE ON 3 X 2 ARRAY IN A 1.3M DIAGONAL FRAME



DEVELOPMENT OF A LARGE AREA, TILED, LIQUID CRYSTAL DISPLAY

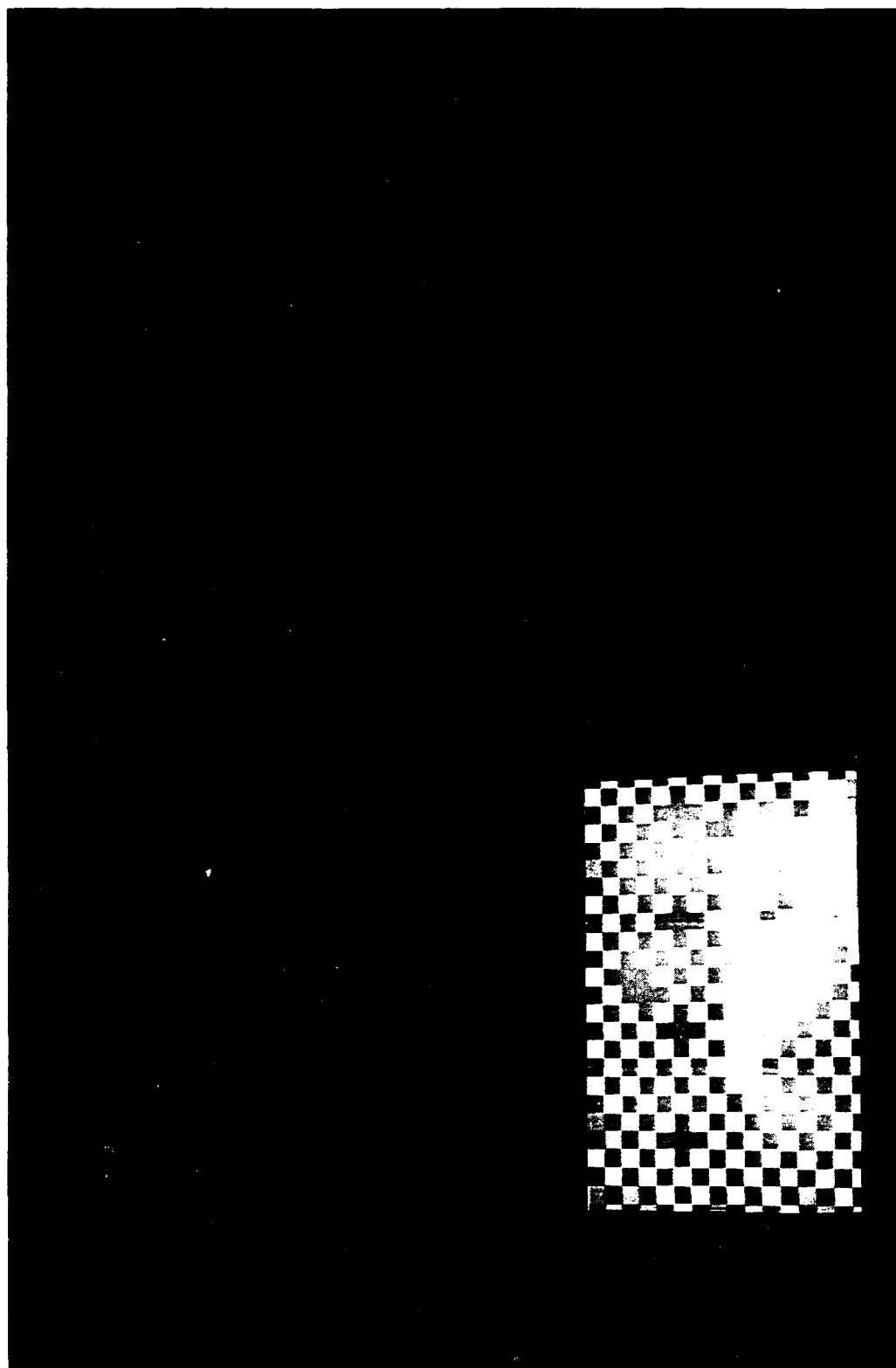


FIGURE 3.6.1-3

PHOTOGRAPH OF GRAPHIC IMAGE ON 3 X 2 ARRAY IN A 1.3M DIAGONAL FRAME

DEVELOPMENT OF A LARGE AREA, TILED, LIQUID CRYSTAL DISPLAY

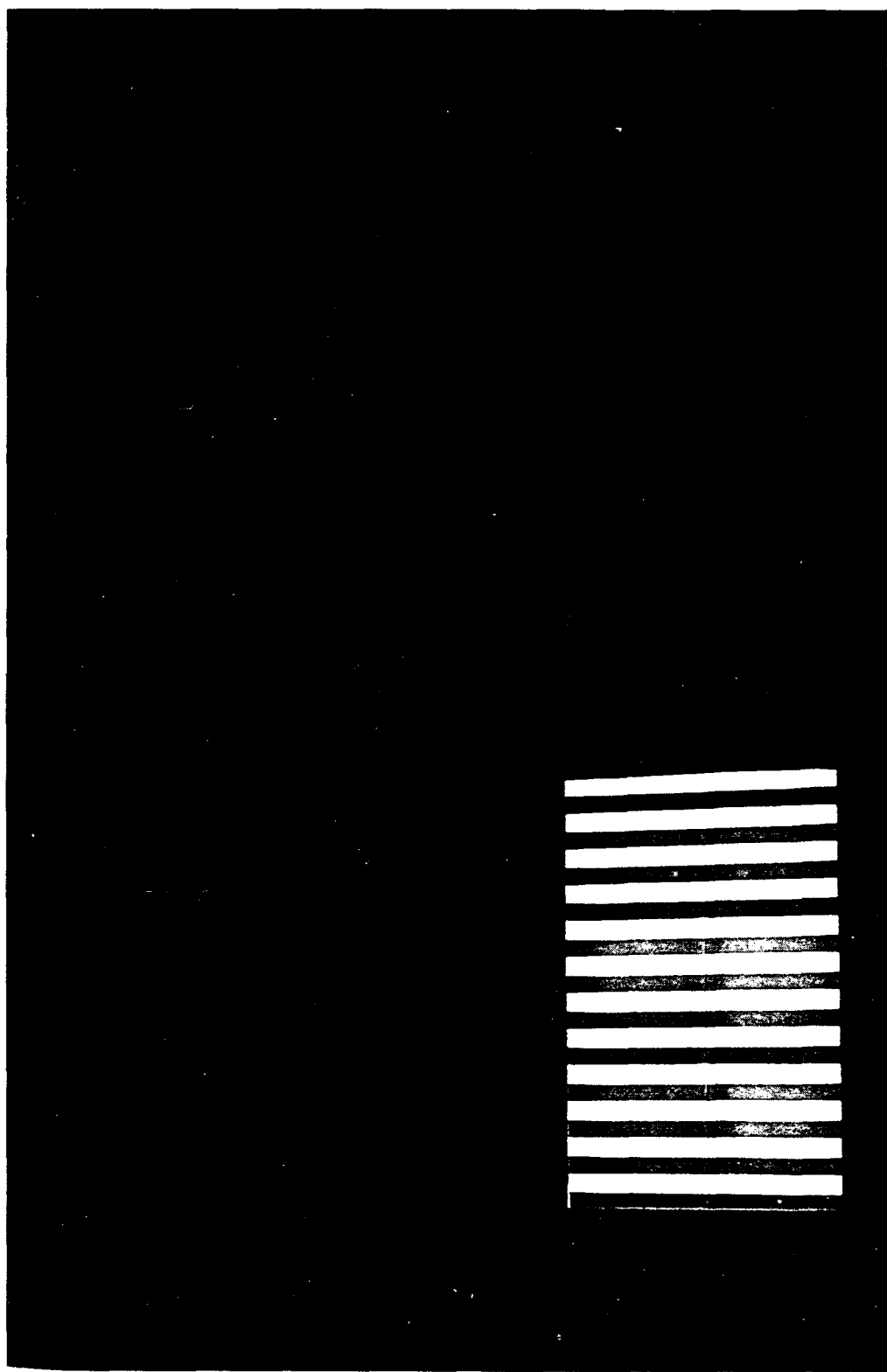


FIGURE 3.6.1-4

PHOTOGRAPH OF GRAPHIC IMAGE ON 3 X 2 ARRAY IN A 1.3M DIAGONAL FRAME

DEVELOPMENT OF A LARGE AREA, TILED, LIQUID CRYSTAL DISPLAY

The evaluation of the 3 X 2 unit to determine the factors that contribute to the visibility of the seams and potential corrective actions indicated the following:

MECHANICAL POSITIONING

- The mechanical positioning of the LCD modules was precise enough to eliminate any visual cues of missing or misregistered pixels at the LCD module seams. The display was mechanically seamless in appearance.

Figure 3.6.1-5 provides close up photographs of the pixels at the LCD module seams.

- The mechanical positioning of the LCD modules did not meet optical requirements for consistent seamless appearance at all the LCD module boundaries. As mentioned earlier, mechanical interference between adjacent LCD modules prevented proper positioning of the LCD modules within the global black mask. This interference in some cases forced the gap between pixels on adjacent LCD modules to be, as much as, 0.406-0.457mm (0.016-0.018") wide, versus the nominal 0.356mm (0.14"), the global black mask was designed for. This LCD module positioning error was sufficient to contribute to light leaks or the appearance of extended width black stripes.
- The cause of the mechanical interference was found to be the sizing and tolerance of the mechanical components in the LCD module assembly. This included:
 - LCD glass sizing that did not properly account for deviations in LCD squareness or "high spots" along the edges of the glass. The nominal glass size was reduced by 0.05mm (0.002") to compensate for these added tolerances. LCDs fabricated in the last batch consistently had an overall size (including flexes) of 130.12mm (5.123"), which is within the original design requirement.
 - Light box and cover size discrepancies, tolerancing, and squareness contributed to instances where the light box or covers of adjacent LCD modules touched. Fabricated as prototypes on CNC equipment, they did get the same tooling and dimensional control processing that they would receive in a volume build. Ultimately, fabricating molded plastic parts will achieve the dimensional consistency required. Rework of some of the light box components was attempted without success, due to the nature of the design.

*DEVELOPMENT OF A LARGE AREA,
TILED, LIQUID CRYSTAL DISPLAY*

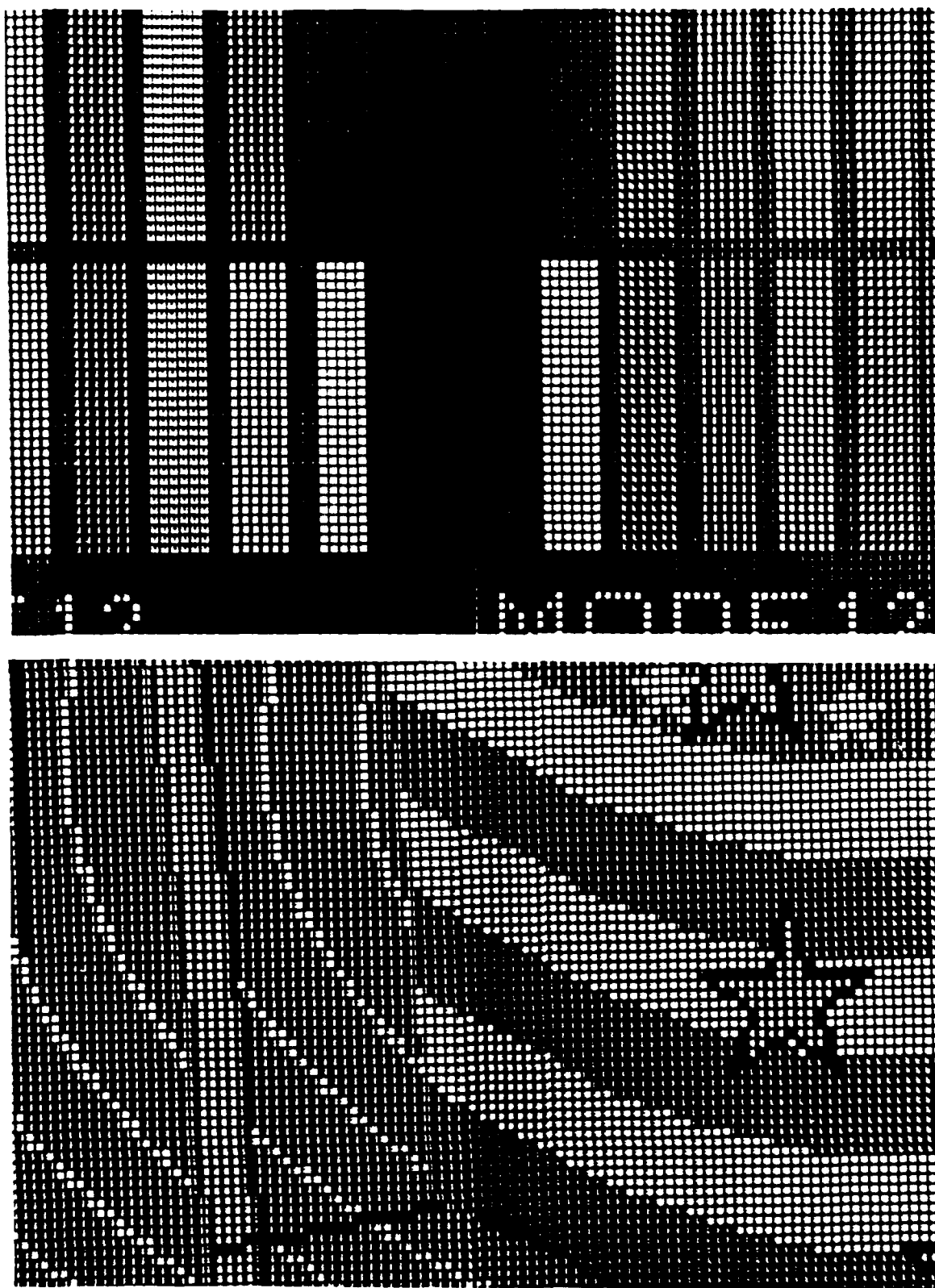


FIGURE 3.6.1-5

PHOTOGRAPHS OF PIXELS AT LCD MODULE SEAMS

DEVELOPMENT OF A LARGE AREA, TILED, LIQUID CRYSTAL DISPLAY

EDGE LUMINANCE UNIFORMITY

- Initially, edge luminance non-uniformity was the most pronounced cue for the location of the seams. The nonuniformity was found to be a combination of problems with the LCD and light box/cover.
- The LCD edge luminance nonuniformity was found to be caused by:
 - Heat damage to polarizers at the edge of the LCD due to flex circuit heat seal process. Added heatsinking and optimizing the heating time effectively eliminated the problem.
 - Cell spacing nonuniformity was the cause of LCD transmission variations at the glass edge. The lamination process, tooling and fixturing were modified until variations in cell spacing and transmission uniformity were no longer observable. Transmission falloff within the last sub-pixel can still be measured. This falloff is now being compensated for by the patterned diffuser used in the backlight system.

Figure 3.6.1-6 provides a graph of the measured LCD transmission from a batch fabricated with the modified processes.

- The edge luminance nonuniformity caused by the light box and cover became apparent after the LCD non-uniformities were eliminated. The cause and corrective actions were detailed in Section 3.4 in the paragraph titled "Backlight Uniformity".

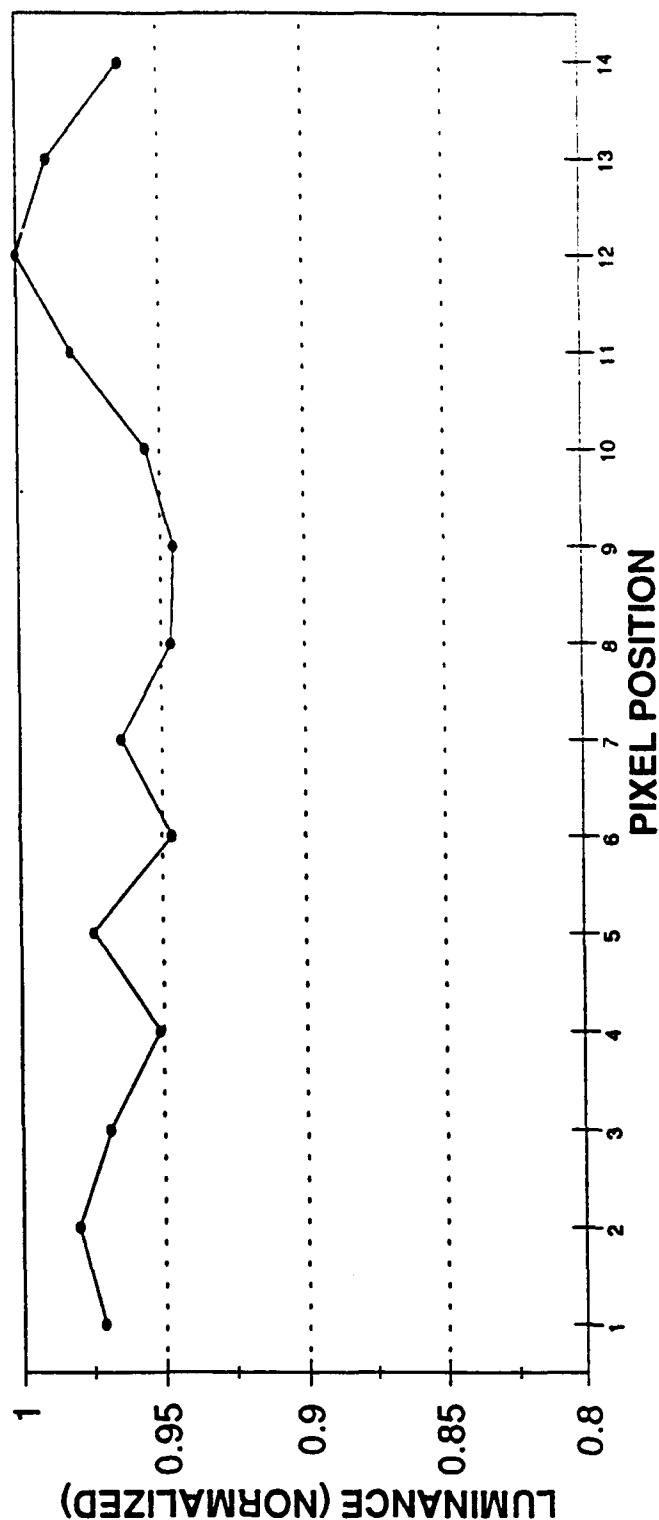
Figures 3.6.1-7 and 3.6.1-8 provides graphs of the measurements of 3 X 2 unit edge luminance before and after corrective actions were implemented.

OPTICAL TILE MATCHING

- Optical matching of LCD modules within typical manufacturing variations was found to be possible.
- The ability to control the drive voltage of the LCDs on individual LCD modules allowed for compensation of LCD transmission variations within a batch.
- The key parameters of contrast and transmission versus voltage provides a good measure for determining the quality of LCD module matching. Small changes in LCD contrast to match LCD module luminance were not observable to the eye.

Table 3.6.1-9 lists these typical parameters for a number of LCDs that appear optically matched in the 3 X 2 unit.

UNIFORMITY OF LCD TRANSMISSION



LCD # C643 is mounted directly over a uniform light source (diffuse fluorescent lamps)

Luminance measurements are made in column 10 starting at the first pixel near the edge of the LCD.

The vertical scan is from pixel 1 to pixel 14 in the above graph.

The luminance values have been normalized to better represent the uniformity analysis

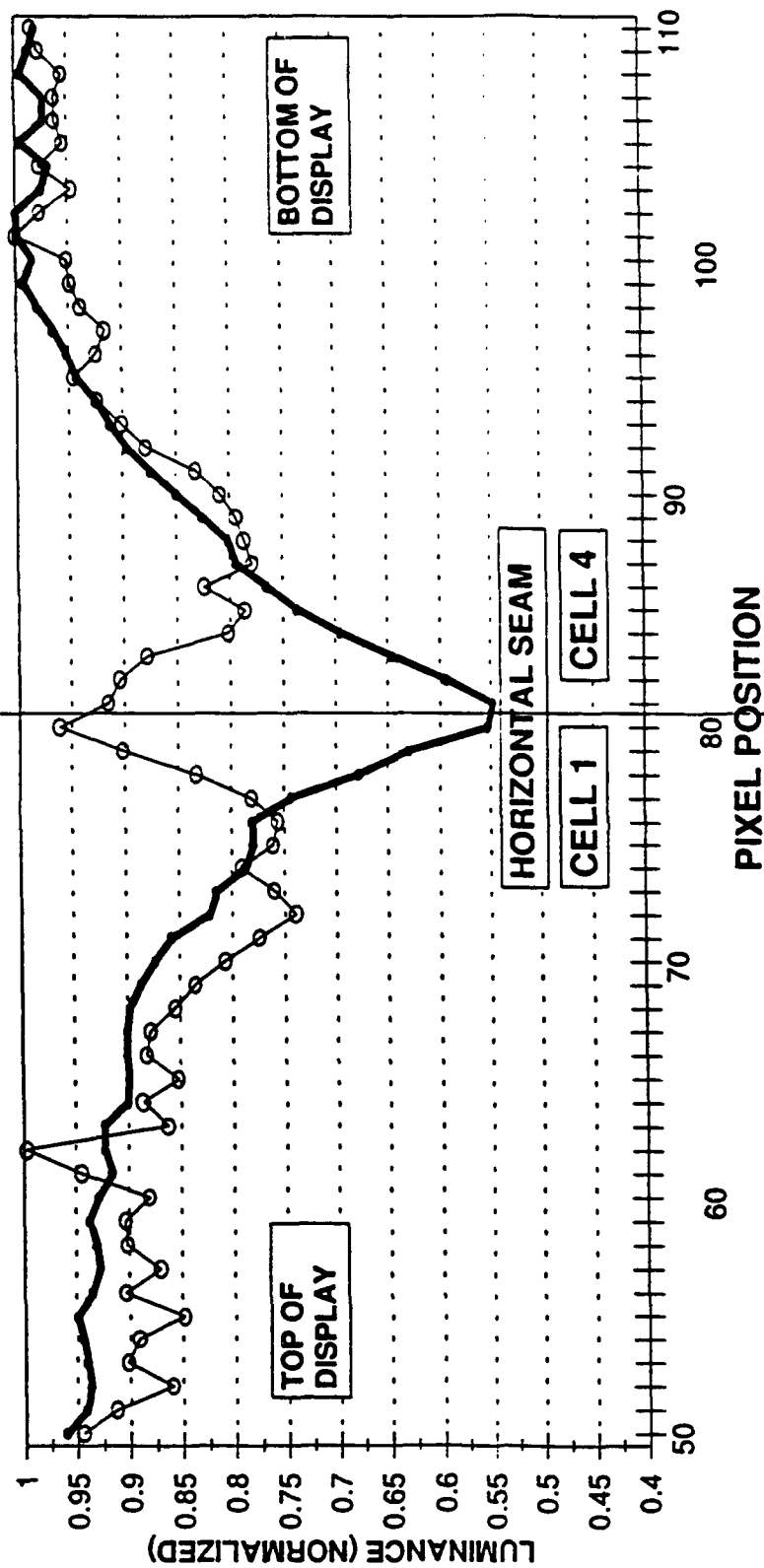
disun004.wb1:lcd4a

Figure 3.6.1-6

UNIFORMITY OF LUMINANCE

3 X 2 ARRAY

VERTICAL SCAN ACROSS HORIZONTAL SEAM



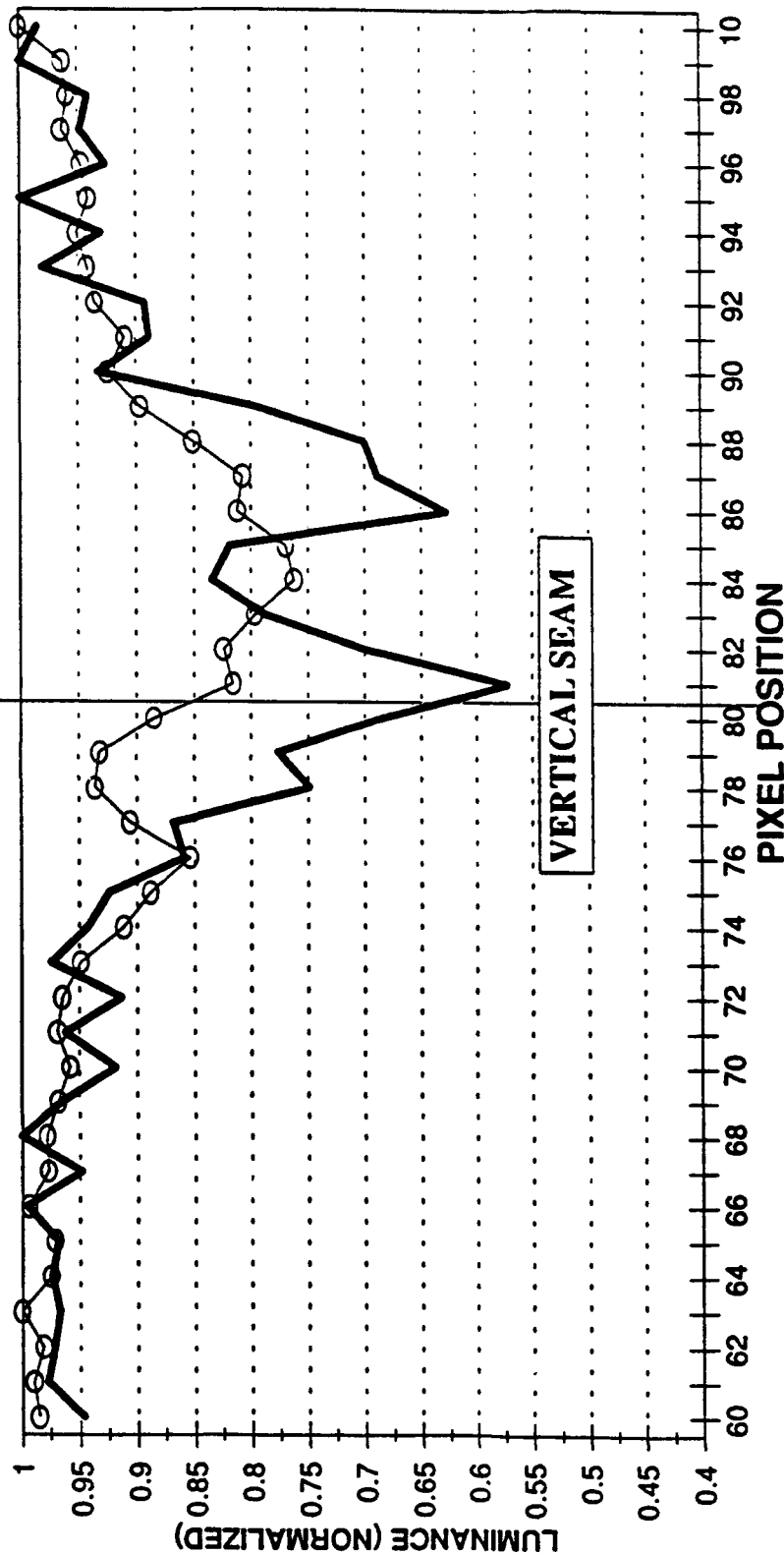
— ORIGINAL JUNE 1993 —○— FINAL SEPT. 1993

EACH SET OF DATA IS NORMALIZED RESPECTIVELY

Figure 3.6.1-7

UNIFORMITY OF LUMINANCE 3 X 2 ARRAY

HORIZONTAL SCAN ACROSS VERTICAL SEAM



— ORIGINAL JUNE 1993 —○— FINAL SEPT. 1993

EACH SET OF DATA IS NORMALIZED RESPECTIVELY

Figure 3.6.1-8

321101NDISUNF05.WB

TYPICALLY MEASURED LCD PARAMETERS

LCD TEST LOG (LCDS FOR TILED ARRAY DESIGN) SUMMARY

TEST DATE	FILE NAME	CELL NO.	DIRECT (0 - 12 VAC)		MULTIPLY EX ANALYSIS*						
			MAXIMUM		CROSSOVER			MAXIMUM			
			CONTRAST	TRANS	% MAX.	VOLT		CONTRAST	TRANS	CONTRAST	TRANS
09/10/93	EODAT13.WB1	C912	418	9.8%	31%	3.9	11.5	2.9%	37.0	9.8%	
09/10/93	EODAT12.WB1	C921	456	10.5%	30%	3.9	11.0	3.0%	36.7	10.5%	
09/19/93	EODAT27.WB1	C923	339	9.5%	35%	4.0	9.5	3.1%	27.0	9.5%	
09/16/93	EODAT20.WB1	C955	199	8.0%	38%	4.1	9.3	2.8%	24.3	8.0%	
09/13/93	EODAT16.WB1	C960	269	8.9%	36%	3.9	7.7	2.9%	21.3	8.8%	
09/24/93	EODAT37.WB1	C968	449	9.8%	32%	4.1	11.2	3.0%	35.0	10.5%	
09/15/93	EODAT18.WB1	C978	271	8.6%	36%	3.9	7.3	2.9%	20.2	8.6%	
09/17/93	EODAT23.WB1	C984	217	8.2%	40%	4.1	7.1	3.0%	17.7	8.2%	
09/19/93	EODAT28.WB1	C988	354	8.7%	35%	4.1	10.1	2.8%	28.8	8.7%	
09/19/93	EODAT30.WB1	C990	207	8.5%	37%	4.1	8.4	2.9%	22.8	8.5%	
09/18/93	EODAT24.WB1	C013	376	9.2%	35%	4.0	9.7	3.0%	27.8	9.2%	
09/18/93	EODAT26.WB1	C015	326	9.0%	35%	4.0	9.6	3.0%	27.5	9.0%	
09/23/93	EODAT36.WB1	C016	391	9.3%	35%	4.0	10.2	3.0%	29.2	9.3%	
09/18/93	EODAT25.WB1	C021	235	8.7%	35%	4.2	8.6	2.8%	24.6	8.7%	
09/15/93	EODAT19.WB1	C029	235	9.2%	35%	3.9	7.1	3.1%	20.2	9.2%	

1463617.wb1.vmb.pdf

*** VI VOLTAGE RANGES FROM 1 TO 12 VAC**

UPT/10 APR

DEVELOPMENT OF A LARGE AREA, TILED, LIQUID CRYSTAL DISPLAY

- Variations of color among LCD modules appeared visually acceptable when the following criteria were met:
 - No large variations in LCD module contrast are present.
 - Polarizer type and alignment orientations were configured the same way on all LCD modules. Polarizer variations are also noticeable as a difference in color shift over viewing angle.
 - The color filter was aligned within acceptable tolerances.
 - The LCD modules are aligned within acceptable tolerances to the global black mask. Mask misalignment is most noticeable as a difference in color shift over viewing angle.

COLOR FILTER REGISTRATION

- Misregistration of the color filter to the LCD contributes to the visibility of seams.
- Maintaining the same distance between adjacent color sub-pixel (blue stripe to red stripe) across LCD module seams is required. Larger gaps between these sub-pixels creates the appearance of a wider black stripe at the seam.
- The design tolerance of 0.05mm (0.002") appears adequate. The process and fixturing developed did not always achieve this tolerance during the assembly of the prototypes. An interim process was developed to allow the use of prototype "cromalin" color filters. Further development of the lamination process and fixturing is required with the use of printed color filters.

GLOBAL BLACK MASK

- The design concept of using a global black mask to hide the mechanical seams was shown to be effective. There are no cues to indicate the location of the mechanical seams when the LCD modules are properly registered with the black mask.
- The interpixel black stripe width of 0.2mm (0.008") within an LCD module was used. This provides sufficient tolerance to prevent slight misalignment of an LCD module to the global mask from hiding a portion of a color stripe which would affect display color.
- The interpixel black stripe width of 0.25mm (0.01") was used over the mechanical seam. This represents a compromise between hiding light leaks at the mechanical seam and creating a visual cue at the seams. At the optimum design viewing distance of greater than ten feet, this difference between inter-module and intra-module black stripe widths was not observable. Further refinement of the stripe widths to optimize the display appearance may be possible.

DEVELOPMENT OF A LARGE AREA, TILED, LIQUID CRYSTAL DISPLAY

3.6.2 LCD OPTICAL PARAMETERS

The LCD optical objectives of this program were twofold:

- To provide sufficient optical performance to demonstrate the feasibility of a tiled display system seamless in appearance.
- To provide a path for improving the optical performance of a tiled system to meet commercial standards.

The LCD optical parameters were measured to provide a baseline for future develop of the display's optical performance.

Table 3.6.2-1 provides a summary of original objectives, measured LCD contrast and transmission and achievable targets based on the data taken.

Figure 3.6.2-2 provides a graph of the typical contrast and transmission versus drive voltage.

3.6.3 OVERALL DISPLAY PERFORMANCE ISSUES

The 3 X 2 unit was subjectively evaluated for other display issues that included:

- Viewing angle
- Display glare
- Required display intensity

VIEWING ANGLE

- The viewing angle of the 3 X 2 display was very poor. Subjectively less than +/- 15 degrees.
- The viewing angle of the 3 X 2 display was basically determined by the optical performance of the LCDs used.
- Parallax between the fluid layer of the cell and the color filter on the front surface of the LCD did not appear to be a problem.

**DEVELOPMENT OF A LARGE AREA,
TILED, LIQUID CRYSTAL DISPLAY**

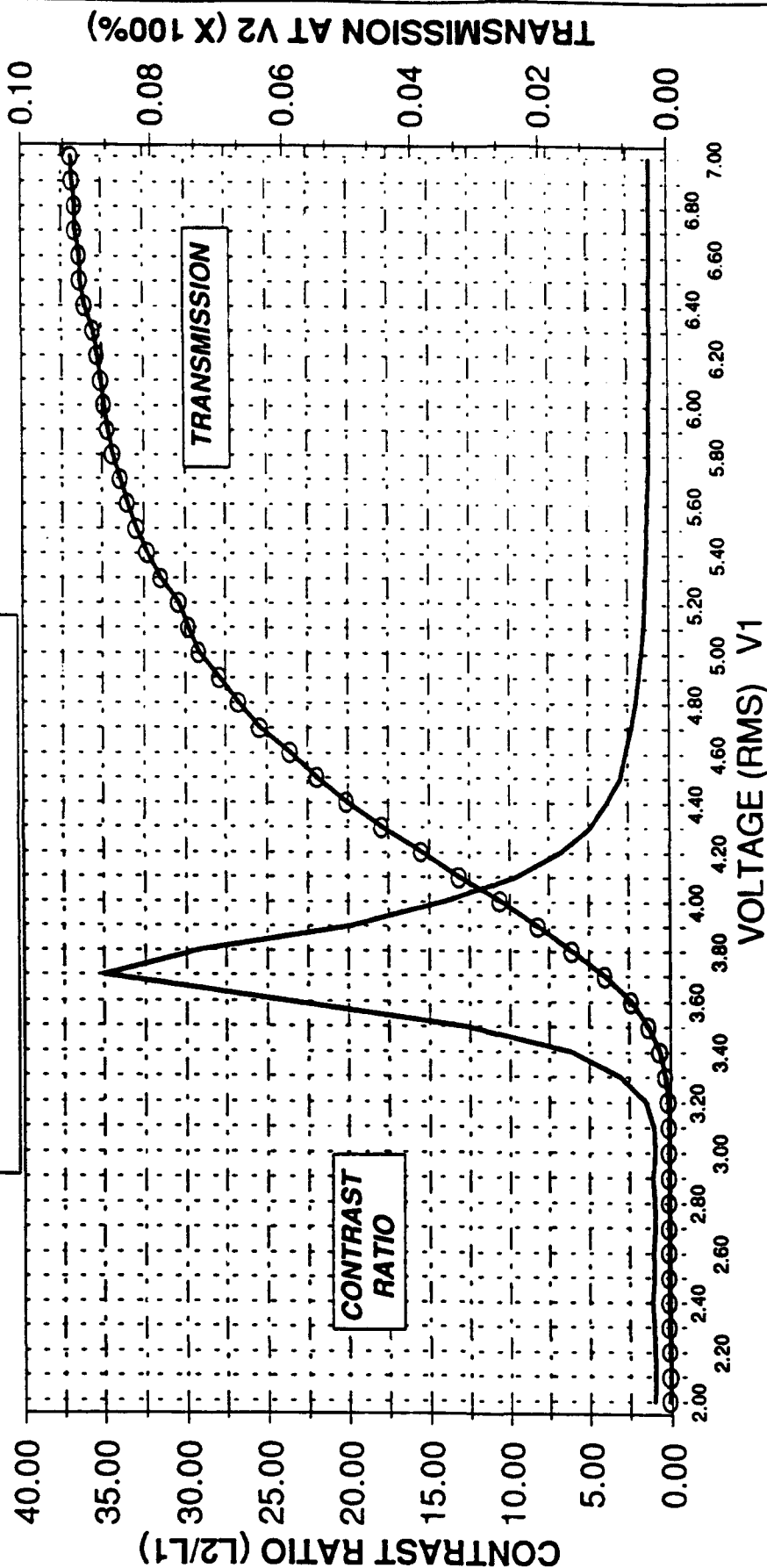
TABLE 3.6.2-1

LCD OPTICAL PARAMETERS

	OBJECTIVE	ACTUAL	ACHIEVABLE
<i>Maximum Sub-Pixel Contrast</i>	> 30:1	27:1	50:1
<i>Maximum Sub-Pixel Transmission</i>	10%	9%	15%

TRANSMISSION / CONTRAST ANALYSIS

MULTIPLEX OPERATION OF LCD



V1 is the "off" voltage, V2 is the "on" voltage
 For each value of V1 a corresponding V2 is calculated based on multiplexing scheme
 Contrast ratio is the luminance at voltage V2 divided by the luminance at voltage V1
 Transmission is the luminance at voltage V2 divided by the background illumination

Figure 3.6.2-2

— CONTRAST —○— TRANSMISSION

TRANS/CONT5/IODAT137

DEVELOPMENT OF A LARGE AREA, TILED, LIQUID CRYSTAL DISPLAY

- The path for widening the display's viewing angle was determined to be a combination of improvement in LCD performance and the addition of a front diffusing screen.
- Various front diffusing materials were subjectively evaluated and appear promising. The selection of a particular material will be based on the optimum tradeoff between viewing angle, contrast and luminance.
- The viewing angle over which the display remains seamless in appearance is an issue. The dark edges of the display appear as seams over wide viewing angles. The absolute angle where this becomes an issue cannot be determined until improved LCDs and a diffuser screen are implemented in the system. Possible corrective actions to mitigate this problem include reflective surface treatments to the glass edge and modifications to the backlight distribution at the glass edge.

DISPLAY GLARE

- No effort to reduce front surface reflections were made on the 3 X 2 unit. Lighting reflections hampered display readability in room ambient lighting conditions.
- The surface reflections were primarily due to the cover glass and global black mask. The cover glass front surface requires an anti-reflective coating. The global black mask (and eventually the diffuser screen) must be optically laminated to the rear of the cover glass.

DISPLAY LUMINANCE

- The display luminance of the 3 X 2 unit was in the range of 136-174 candela/m² (40-80 fL) depending upon the setting of the LCD drive voltage. Subjectively, a drive voltage setting that produced 171 candela/m² (50 fL) gave the best contrast versus transmission tradeoff.
- Based on information and feedback provided by potential users an increased luminance would be desirable depending on the quality of the anti-reflective properties of the display.
- A luminance of 513 candela/m² (150 fL) appears achievable. Increased LCD optical performance will provide a significant gain in transmission. Improvements in other optical components (i.e., color filters, diffusers, etc.) are expected to increase display luminance. The option to increase the fluorescent lamp lumen output also exists.

DEVELOPMENT OF A LARGE AREA, TILED, LIQUID CRYSTAL DISPLAY

3.7 ELECTRONIC ASSEMBLIES

The display system electronics was designed and implemented as follows:

INTERFACE ELECTRONICS

- The interface design was developed around the use of a Cirrus Logic GD6410 and GD6340, passive matrix LCD, VGA controller chip set.
- The operation and output characteristics of the GD6410 and GD6340 were studied and documented in order to insure that gray shade display data could be properly passed through to the subcontrollers.
- The interface design was implemented on two (2) printed circuit boards (PCBs). The first PCB contained the line interface and timing logic. The second PCB contained six (6) identical sub-controller circuits (one (1) for each row of LCD modules).
- The interface circuit was designed using programmable logic arrays (PLAs) minimizing the part count and area required.
- The interface circuit PCBs were laid out and fabricated. The PCBs were populated with components. Debug and checkout of circuit operation was not completed prior to the end of the program.

LCD DRIVER ELECTRONICS

- The LCD driver electronics was implemented using SMOS SED1600 and SED1610 column and row drivers.
- The driver circuit PCB were designed for an automated surface mount assembly process.
- Approximately thirty (30) PCBs were populated during the program.
- The driver circuit operated as designed including the programmable drive voltage control function.
- The addition of a temperature compensation circuit will be required in order to eliminate any effect on the display until the system temperature stabilizes.

DEVELOPMENT OF A LARGE AREA, TILED, LIQUID CRYSTAL DISPLAY

VGA CONTROLLER CARD

- A Cirrus Logic 6410/6340 evaluation card was obtained and setup on a 386 IBM PC clone.
- Operation was verified using a Sharp color STN, VGA module.
- Operation with the display interface circuits was not verified prior to the end of the program.

POWER SUPPLIES

- External DC power supplies were used to operate the 3 X 2 unit.
- 5 VDC, 12 VDC, and -28VDC low profile supplies were identified for use in the 1.3M (51") display chassis but were not purchased prior to the end of the program.
- Commercially available, electronic fluorescent ballasts were obtained for the 3 X 2 unit. They were mounted external to the unit.
- Commercially available, low profile, four (4) lamp, electronic ballasts were obtained for use in the 1.3M (51") display.
- Electronic dimming of the fluorescent lamps will be required to balance increased display luminance for both ambient and darkened room lighting conditions.

DEVELOPMENT OF A LARGE AREA, TILED, LIQUID CRYSTAL DISPLAY

4.0 FUTURE SYSTEM DEVELOPMENTS

The future system developments outlined in this section are intended to optimize the optical performance of the tiled display system developed by this program with the goal of demonstrating commercially acceptable display performance.

The areas of optimization include:

- LCD optimization
- Backlight optimization
- Color filters
- Front diffuser
- Mechanical registration

Table 4.0-1 summarizes the inter-relation between the tiled display system performance and the key elements.

4.1 LCD OPTIMIZATION

The objective of work in this area is to improve the optical performance of the LCDs used in the tiled display system. This includes:

- Improved contrast/transmission
- Improved viewing angle
- Improved color characteristics
- Improved transmission uniformity at the edge of the display
- Improved response time for video rate operation

The optical performance targets for the LCD include:

- Contrast/transmission: 30:1 pixel contrast at 15% trans.
- Viewing angle: +/- 30 deg. horizontal; +/- 20 deg. vertical
- Color: match to color filter design
- Transmission at LCD edge: < 10% trans. falloff
- Response time: < 50 ms

The strategy is to determine the display technology available that provides the best performance versus cost trade off. Three (3) candidates would be pursued. They are:

- TN LC technology which appear to require the added cost of a dual cell configuration to obtain good optical performance.

**DEVELOPMENT OF A LARGE AREA,
TILED, LIQUID CRYSTAL DISPLAY**

TABLE 4.0-1

TILED DISPLAY SYSTEM/PERFORMANCE VERSUS KEY ELEMENTS

OPTICAL ELEMENTS										
PARAMETERS	BACKLIGHT SYSTEM					LCDS				
	LAMPS	LIGHT BOX	LIGHT BOX COVER	LIGHTING DIFFUSER	CELLS	POLARIZERS	ASSEMBLY	COLOR FILTER	BLACK MASK	VIEWING DIFFUSER
SUBJECTIVE										
SEAMS		X	X		X				X	
SHADOWS				X	X	X	X			
QUANTITATIVE										
LUMINANCE	X	X								
TRANSMISSION			X	X	X	X	X	X	X	X
UNIFORMITY		X	X	X	X		X	X		X
CONTRAST					X	X		X		
CHROMATICITY	X							X		
VIEWING ANGLE					X	X	X			X

RPT1130ARP

DEVELOPMENT OF A LARGE AREA, TILED, LIQUID CRYSTAL DISPLAY

- STN LCD technology, whose optical performance must be shown to be adequate for this application, has potential cost advantages.
- AMLCD technology, with the best proven display performance, must be shown to be available at an acceptable cost for this application.

4.1.1 PROTOTYPE LCD OPTIMIZATION

The prototype tiles developed during this program used dual cell TN LCD technology. The development tasks required to optimize the prototype cell include:

- Optimizing buffing/polarizer orientations to improve the viewing angle and contrast of the LCD.
- Optimizing polarizers selected for the best contrast, versus transmission versus viewing angle trade off.
- Minimizing non-uniformities at edge pixels by eliminating anomalies near the epoxy seals.
- Prototyping first minima LCD to evaluate the trade between improved optical performance and the increase in manufacturing difficulty.
- Development of a retardation film to improve the viewing angle of the display.

4.1.2 STN EVALUATION & DEVELOPMENT

The objective of this work is to evaluate the optical performance of STN technology and prototype LCDs configured for this application. The areas of evaluation include:

- Low multiplex rate optical performance when configured in a normally dark mode.
 - Contrast
 - Transmission
 - Viewing angle
 - Response time
 - Color
- Manufacturability and cost of STN LCDs configured for thin seals and edge contacts.
- Identification of potential volume suppliers and obtain prototype LCDs for evaluation.

DEVELOPMENT OF A LARGE AREA, TILED, LIQUID CRYSTAL DISPLAY

4.1.3 AMLCD SOURCING

The objective of this work is to identify potential sources of TFT substrates or displays configured for use in the tiled display system. This includes:

- Evaluating commercially available AMLCDs for optical performance.
- Developing an understanding of manufacturers design rules and processes.
- The development of a AMLCD specification defining the design requirements that are compatible with existing suppliers and three tiled display system design requirements.
- Developing firm quotations on cost and delivery of both prototype and volume quantities of AMLCDs.

4.2 BACKLIGHT OPTIMIZATION

The objective of the work in this area includes:

- Refinement of backlight uniformity
- Increased backlight luminance

The targeted improvements include:

- Light box/cover luminance non-uniformity < 10%
- Development of a white patterned diffuser design
- > 50% increase in fluorescent lamp luminance

The tasks to be completed include:

- Optimization of the light box and cover shapes.
- Development of a screen printing process for the white patterned diffuser design.
- Modification of the electronic ballasts to increase fluorescent lamp luminance.

4.3 COLOR FILTERS OPTIMIZATION

The goal as a minimum is to achieve the color quality of existing commercial passive matrix displays at much higher display luminance levels. A precise color specification will be developed as a part of this task.

DEVELOPMENT OF A LARGE AREA, TILED, LIQUID CRYSTAL DISPLAY

The tasks to be completed can be summarized as follows:

- Complete the evaluation of both the cromalin and printed color filters developed for the 3 X 2 unit LCDs. This includes:
 - Mechanical dimensions - R,G,B stripe registration
 - Uniformity of hue, saturation, transmission, chromaticity
 - Materials used - substrate, inks
 - Addition of protective coating for protection during LCD lamination process
 - Reliability/environmental resistance - temperature, humidity, UV
- Evaluate spectral performance of all optical components in the system. This includes spectroradiometric measurements to be made on the following:
 - Fluorescent lamps
 - Light box plastic & paint
 - Light box diffuser materials
 - LCD polarizers options
 - LCD assembly
 - Black mask assembly
 - Front diffuser screen/cover glass options
- Develop color specifications for the system as follows:
 - Review published specifications for various color display systems.
 - Optically test and evaluate a sample of available color LCDs.
- Evaluate other color filter techniques this includes:
 - Brewer Science supplied glass color filters
 - Carnegie Mellon University filter developments
 - Printing color filters on other media (polarizers, diffusers, etc.)

4.4 FRONT DIFFUSER DEVELOPMENT

The first objective of work in this area is to widen the viewing angle of the tiled display system beyond the viewing angle inherent to the LCDs by the use of a global diffuser placed on the front of the LCD modules. The subjective target is to widen the viewing angle without reducing the contrast and sharpness of the display to unacceptable levels.

A second objective is to minimize specular reflections from the front surface of the display.

DEVELOPMENT OF A LARGE AREA, TILED, LIQUID CRYSTAL DISPLAY

The tasks to be completed include:

- Selection and testing of various materials available for this type of application.
- Prototyping a front diffuser for the 3 X 2 unit.
- Development of a specification for the front diffuser screen.
- Addition of antireflective coatings and lamination of optical components used on the face of the display.

4.5 MECHANICAL REGISTRATION OPTIMIZATION

The objective of the work in this area is to improve the consistency of the tiled display system's seamless appearance by more precisely defining acceptable registration tolerances based on actual fabricated components. The tolerances to be looked at include:

- LCD and lighting system component sizes
- Color filter size and registration to the LCD
- Black mask registration

The tasks to be completed include:

- Review of the mechanical component tolerances that affect inter-module pitch
- Review of color filter/ LCD registration
- Modification of the component fabrication specifications.
- Fabricating components to verify the modifications are effective.

4.6 PRODUCT PROTOTYPE DEVELOPMENT

The overall objective of the future technical developments outlined above is to integrate them into a prototype of a product that is targeted for a specific application.

Depending on the optical performance achieved and the associated cost, Magnascreen will identify a specific customer applications and build a large area tiled display prototype.

DEVELOPMENT OF A LARGE AREA, TILED, LIQUID CRYSTAL DISPLAY

5.0 POTENTIAL PRODUCTS AND MARKETS

5.1 POTENTIAL PRODUCTS

The large area, tiled, display system developed by Magnascreen makes it ideally suited for products that require one or more of the following characteristics:

- Display sizes of 1.3m (51") to 2.7m (105") for group viewing at distances greater than 5-10 feet.
- Large active display area without suitable depth, weight, volume or location for projection systems.
- Large displays to be viewed in ambient light conditions.
- The sharpness and linearity of a direct view display not obtained by projection systems.
- The ability to customize display sizes and row /column configurations.
- Displays with up to 2000 X 2000 color pixels at intermediate display densities (15-25 LPI).

Examples of potential products include:

- 1.3M (51") 640 X 480 VGA color monitors
- 2.0M (80") 1024 X 768 high resolution color monitor
- 2.7M (105") 1280 X 1024 high resolution color monitor
- 2.0M (80") 1550 X 1100 HDTV color monitor
- Custom configured displays for command, control and status displays.

Figure 5.1-1 provides a photograph of the 1.3M (51") 640 x 480 VGA mock-up.

5.2 POTENTIAL MARKETS

The potential market for Magnascreen's large area, tiled display systems can be characterized as follows:

DEVELOPMENT OF A LARGE AREA, TILED, LIQUID CRYSTAL DISPLAY



FIGURE 5.1-1

640 X 480 VGA SYSTEM MOCKUP PHOTOGRAPH

DEVELOPMENT OF A LARGE AREA, TILED, LIQUID CRYSTAL DISPLAY

- Professional large area display systems - High cost, high performance, often custom configured display systems for applications at:
 - Trade show presentations
 - Conventions
 - Stock markets
 - Airport advertising
 - Casinos
 - Theme parks
 - Sporting events
- Professional presentation display systems - High quality display systems for business applications including:
 - Corporate conference rooms
 - Corporate training centers
 - Group video conferencing
- High end consumer applications
 - HDTV systems

The discriminators between these potential markets are price and performance. Magnascreen has done marketing research to define the market size and price structure.

Figure 5.2-1 summarizes the potential market sizes and pricing structure.

Magnascreen's tiled display system design has the flexibility to use AMLCD technology for the high performance high cost systems and various passive matrix LCD technology for less demanding lower cost applications.

Figure 5.2-2 illustrates potential system pricing as a function of the LCD technology used in the tiles.

In summary, Magnascreen's large area tiled display system, as developed, using current active and passive matrix LCD technology available, can be used to manufacture cost effective, main stream products. These products can serve both government and industry applications for professional display systems. Future advances in lower cost, higher performing LCD technologies, such as plastic STN LCDs, will allow system pricing compatible with the high end consumer market.

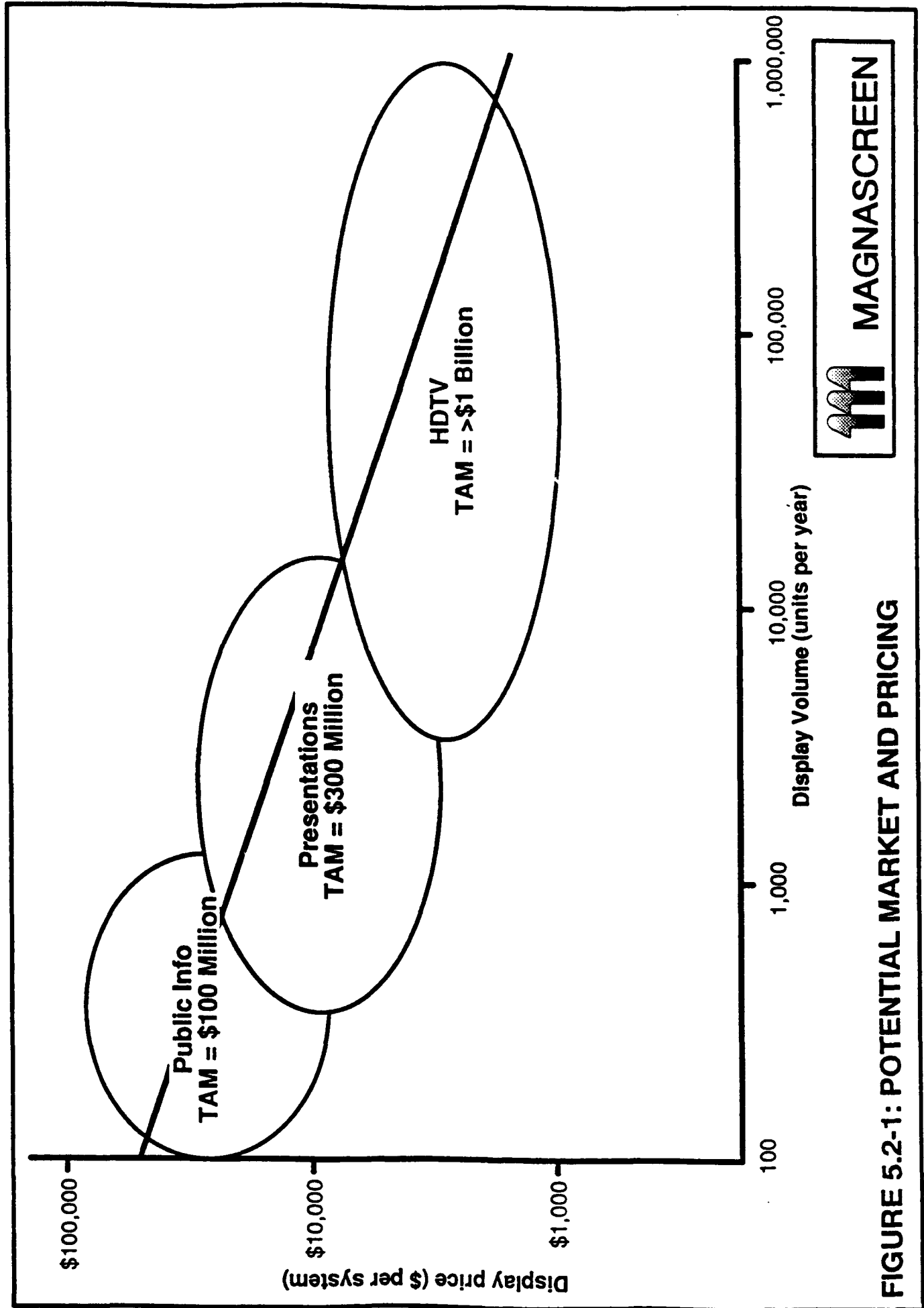


FIGURE 5.2-1: POTENTIAL MARKET AND PRICING

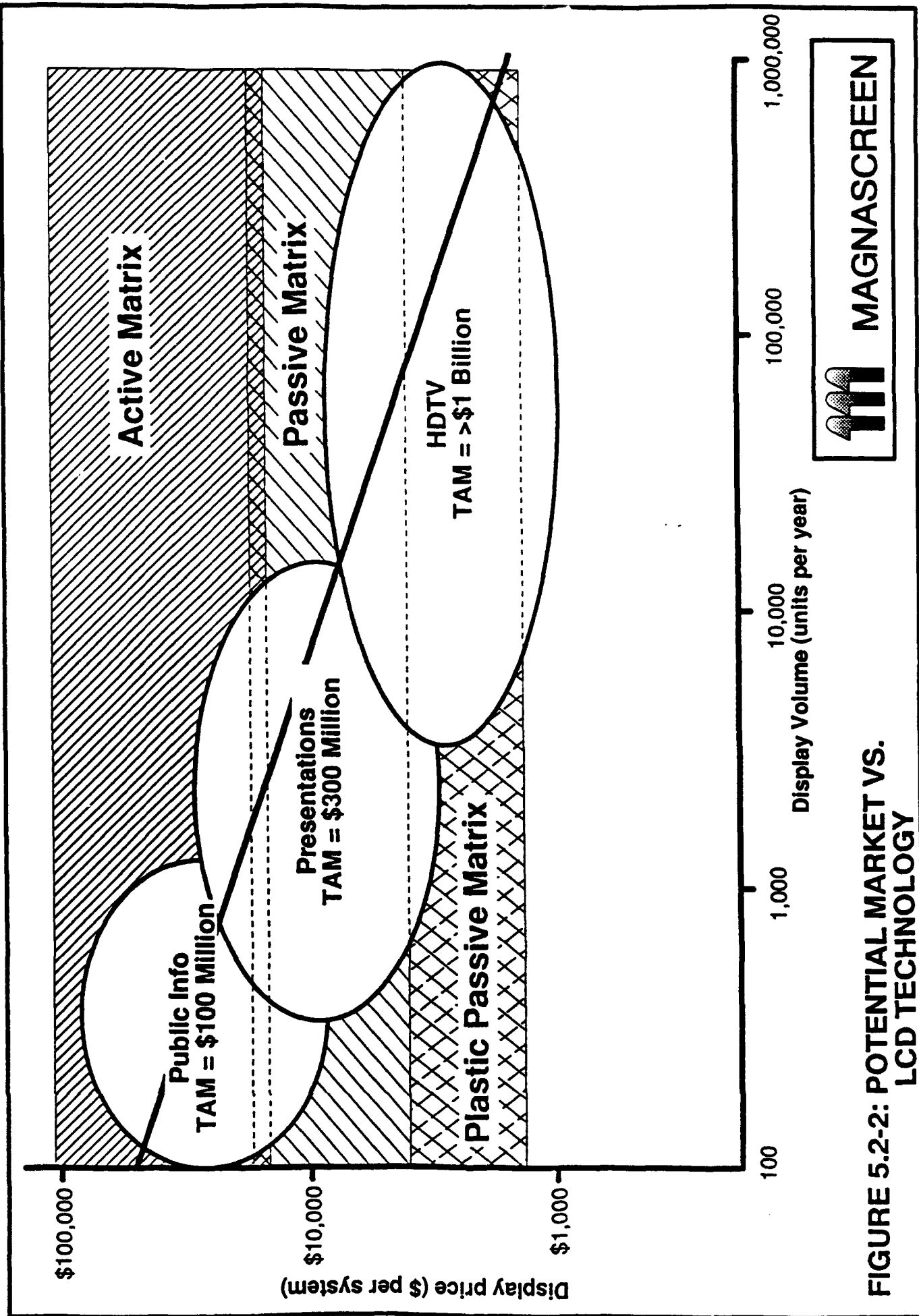


FIGURE 5.2-2: POTENTIAL MARKET VS. LCD TECHNOLOGY